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Assessment of Watershed Vulnerability to Climate Change for the Uinta-Wasatch-Cache and Ashley National Forests, Utah

Janine Rice, Tim Bardsley, Pete Gomben, Dustin Bambrough,
Stacey Weems, Sarah Leahy, Christopher Plunkett,
Charles Condrat, and Linda A. Joyce



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Abstract

Watersheds on the Uinta-Wasatch-Cache and Ashley National Forests provide many ecosystem services, and climate change poses a risk to these services. We developed a watershed vulnerability assessment to provide scientific information for land managers facing the challenge of managing these watersheds. Literature-based information and expert elicitation is used to define components of watershed sensitivity and exposure to climate change. We also define the capacity of watershed function, habitats, and biota to adapt to the expected changes. Watershed vulnerability is scored high for the Wasatch Mountain Range and moderate to high for the Uinta Mountains. These watersheds are driven by a snow-dominated hydrologic regime, and they have a high sensitivity to the projected increases in drought, heat, and flooding. More evaporation, snowpack loss, and earlier snowmelt are expected to shift the timing of runoff earlier and lower streamflow. The loss of snowpack is projected to be especially pronounced in the Wasatch Range. The effects from climate change can be compounded by the non-climate stressors of fire and land uses. Adaptation to these changes is enhanced when watersheds are in good functioning condition. Management actions can serve as an iterative process that builds resilience and can assist transitions to new states under a changing climate.

Keywords: sensitivity, adaptive capacity, extreme events, Wasatch Range, Uinta Mountains, Uinta-Wasatch-Cache National Forest, Ashley National Forest

Authors

Janine Rice is a Research Ecologist with Rice Consulting LLC.

Tim Bardsley is a Senior Service Hydrologist with the National Weather Service in Reno, Nevada.

Pete Gomben is the Environmental Coordinator with the U.S. Forest Service, Uinta-Wasatch-Cache National Forest in South Jordan, Utah.

Dustin Bambrough is the Ecosystem Staff Officer with the U.S. Forest Service, Ashley National Forest in Vernal, Utah.

Stacey Weems is a Soil Scientist with the U.S. Forest Service, Uinta-Wasatch-Cache National Forest in South Jordan, Utah.

Cover photo: *Wasatch Range Watershed (photo: Brendan Waterman, Uinta-Wasatch-Cache National Forest).*

Sarah Leahy is a Soil Scientist with the U.S. Forest Service, Ashley National Forest in Vernal, Utah.

Christopher Plunkett is a Forest Hydrologist with the U.S. Forest Service, Ashley National Forest in Vernal, Utah.

Charles Condrat is a Hydrologist with the U.S. Forest Service, Uinta-Wasatch-Cache National Forest in South Jordan, Utah.

Linda A. Joyce is a Quantitative Research Ecologist at the U.S. Forest Service, Rocky Mountain Research Station in Fort Collins, Colorado.

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Watershed Vulnerability Summary

Uinta-Wasatch-Cache and Ashley National Forests:

Watersheds in the mountainous terrain of these National Forests are dominated by a snow-driven hydrologic regime. Runoff peaks in May–June during the spring snowmelt pulse, and flows are low during late summer, fall, and especially winter. Watersheds in these National Forests provide many ecosystem services: snowmelt provides water for human uses, some of which is stored in reservoirs and redistributed through tunnels, canals, and pipelines, often across watershed boundaries. Streams, ponds, lakes, wetlands, and fens provide habitat for a variety of fish and wildlife. In the context of watershed processes, vegetation provides erosion control on hillslopes and stream banks, as well as food for wildlife. The large human population concentrated along the Wasatch Range, and smaller communities around these National Forests use these watersheds for recreational activities such as hiking, camping, fishing, and skiing.



Figure 1—Watersheds on the Uinta-Wasatch-Cache National Forest (photo: Brendan Waterman, Uinta-Wasatch-Cache National Forest).

Watershed Vulnerability to Climate Change

Wasatch Range:
High

Uinta Mountains:
Moderate to High

Current Conditions: A majority of watersheds are functioning in good to moderate condition, but some are affected by fire, bark beetle outbreaks, roads and trails, invasive species, pollution, and degraded riparian and aquatic habitats.

Exposure: Warmer air and stream temperatures, less snow and more rain especially in the Wasatch Range, lower annual stream flow as a result of more evaporation, and smaller spring peak flows are projected. Periods of drought could be more frequent, intense and longer. Flooding events may become more extreme. Extreme heat events are likely to become more common. These changes in exposure are projected to be more pronounced at lower elevations compared to upper elevations of the Wasatch Range and Uinta Mountains.

Sensitivity: Hydrologic function is sensitive to disruption by climate extremes. Decreased stream flow resulting from drought reduces sediment supplies that maintain channel function. Heat can stress biota. Floods can provide maintenance benefits to stream channels, but can damage infrastructure, restructure streams, reduce riparian plant cover, and cause erosion or debris flows, especially after fire events.

Adaptive Capacity: Many management options are available to enhance the resilience and adaptive capacity of watersheds to climate change and non-climate stressors.

Non-climate Stressors: Fires have reduced vegetation cover and altered runoff processes. Bark beetle outbreaks have changed forest structure. Water diversions and groundwater withdrawals, recreational uses, roads, agricultural and urban land uses, dams, grazing, and energy development have contributed to air and water pollution. These stressors have altered water chemistry, damaged riparian areas, introduced invasive species, fragmented streams, and reduced stream flow in some watersheds.

Introduction

Climate-driven changes associated with recent temperature warming have become increasingly apparent in western United States landscapes over the past decades. More frequent and severe fire and insect outbreaks, less snowpack at mid- and low elevations, and shifts to earlier timing of snowmelt and stream runoff have been linked to recent warming (Bentz 2009; Stewart 2009; Stewart et al. 2005; Westerling et al. 2014). Future warming is projected to add another 2 to 6 °F to average temperatures by mid-century (see Appendix A, figs. A1–A6). This warming may combine ecological impacts with existing stressors in complex ways.

Natural resource managers are developing options to help ecosystems adapt to climate change, and vulnerability assessments are being used to inform adaptation development. Vulnerability assessments use factors of vulnerability to characterize exposure, sensitivity, and adaptive capacity. The character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity to those changes, and its resilience and adaptive ability to cope with changes, are all factors that when combined define vulnerability (Glick et al. 2011). Vulnerability assessments impart an understanding of what components of ecosystems and the services they provide are at risk from a changing climate, why they are vulnerable, and how existing stressors may interact to exacerbate the vulnerability. The knowledge gained serves as a platform for land managers to identify and prioritize strategies and activities that can help ecosystems cope and adapt to climate change (Glick et al. 2011). This report is part of a collaborative effort between the Rocky Mountain Research Station and the Uinta-Wasatch-Cache and Ashley National Forests (NFs) in which we assess the vulnerability of watersheds to climate change.

We assess components tied to the hydrologic function of a watershed, as well as aquatic animal species, and the riparian and upslope vegetation. We synthesize current scientific information in the literature, rank vulnerability using seven criteria, and engage scientific experts and National Forest managers to review vulnerability rankings and the text supporting the rankings (summarized in Appendix B, table B1). Gaps in knowledge are also revealed where information is limited or non-existent. The assessment is intended to form an initial literature-based foundation of scientific information on vulnerability at a broad level that can be updated as more studies and information become available. The information can also be used in forest planning and NEPA (National Environmental Policy Act) documents. A watershed workshop for National Forest managers was held in May 2015 that facilitated the discussion of potential management options of watersheds undergoing climate change on the Uinta-Wasatch-Cache and Ashley NFs.

Method of Vulnerability Assessment

Uinta-Wasatch-Cache and Ashley National Forests Watersheds

Watersheds of the Uinta-Wasatch-Cache and Ashley National Forests of northeastern Utah cover the mountainous terrain of the Wasatch Range, the Stansbury Mountains, and the east-west trending Uinta Mountains (figs. 2 and 3). The Uintas have the highest elevations in the State of Utah, reaching over 13,000 feet. The Wasatch Range and Stansbury Mountains (called the Wasatch Range from here forward) have steeper topography and peaks reaching up to about 11,000 feet.

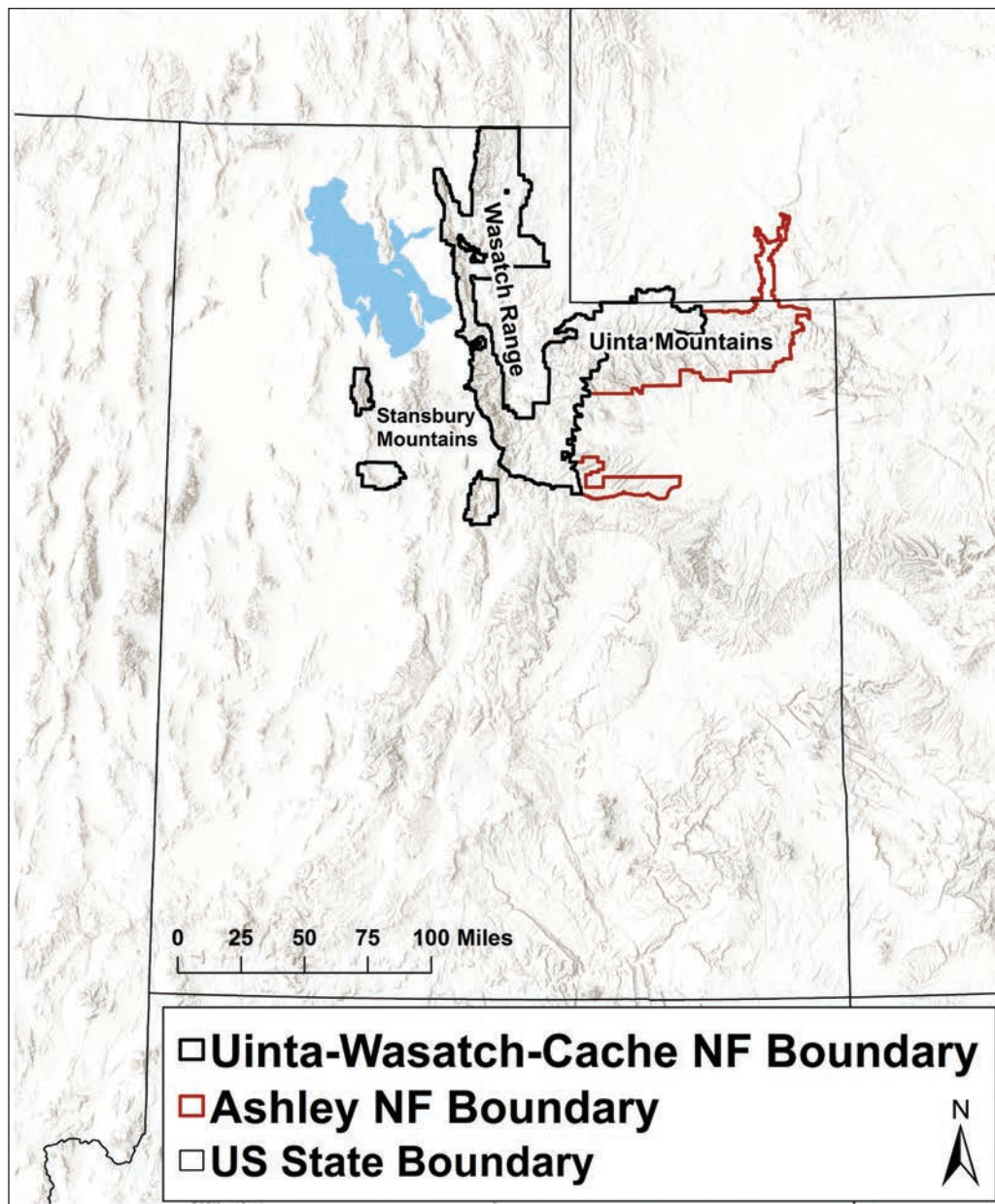


Figure 2—The Wasatch Range, Stansbury, and Uinta Mountains of Utah (Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community).

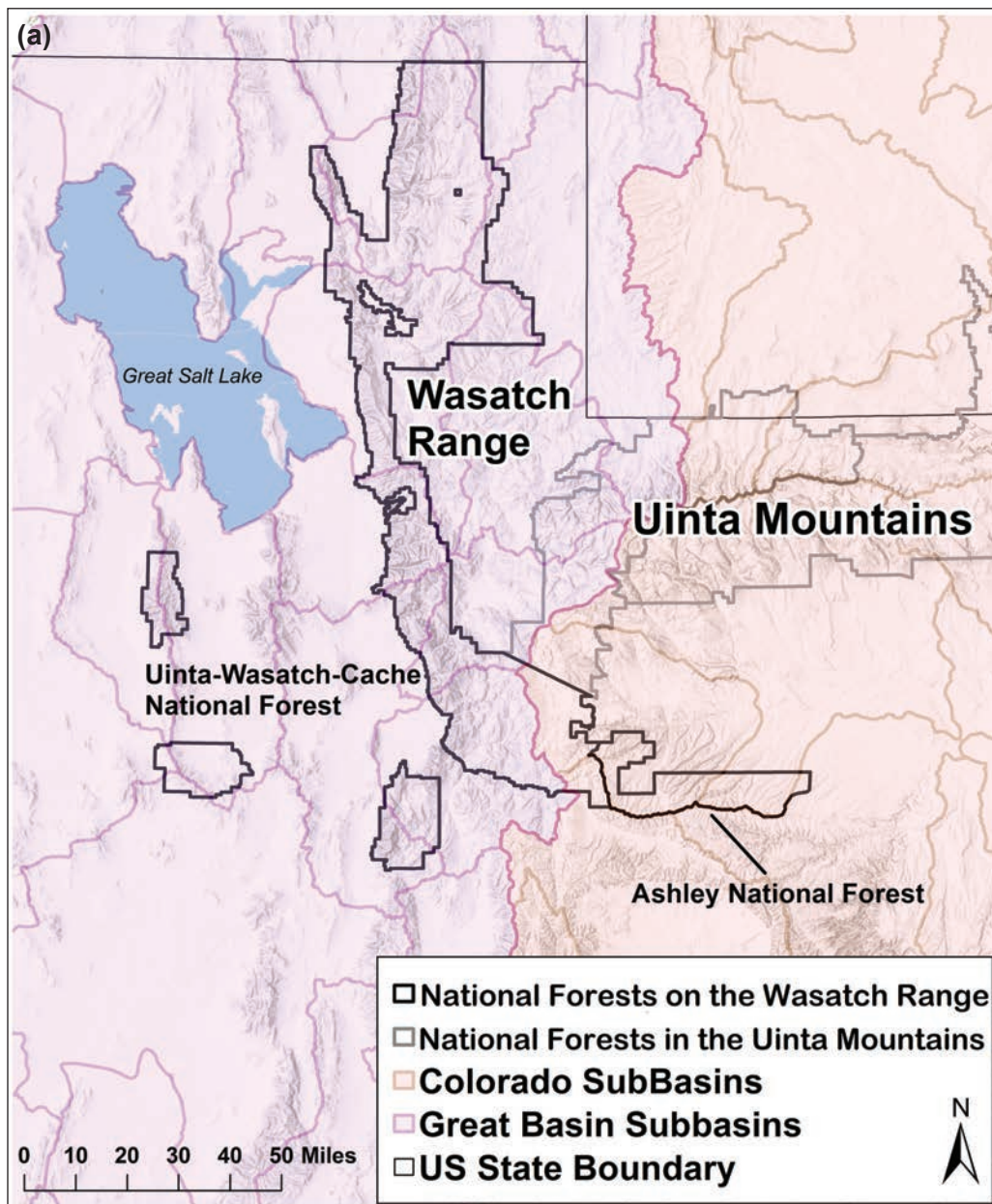
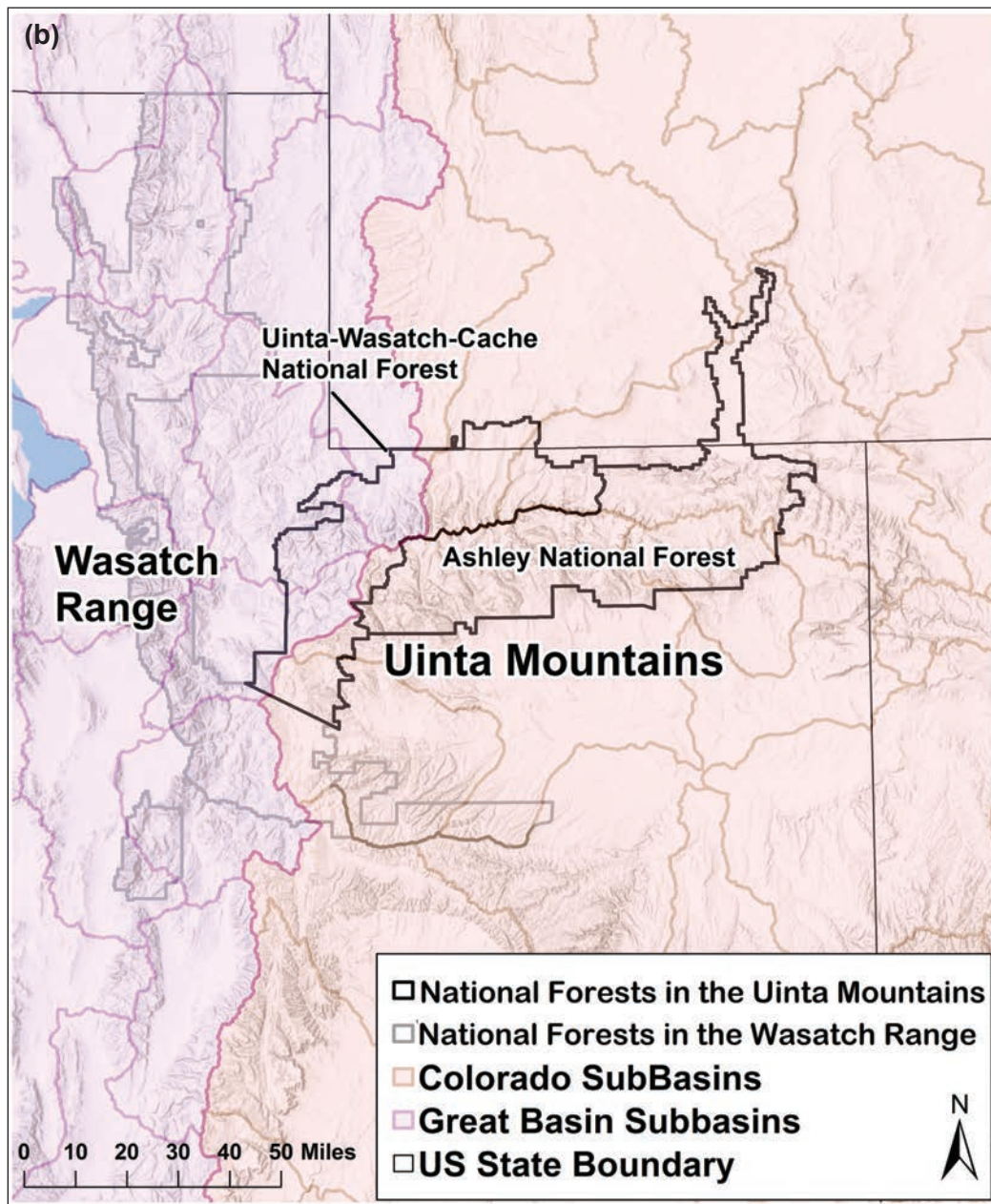


Figure 3—Wasatch Range (a) and Uinta Mountain (b) sub-basin watersheds of the Colorado River and Great Basin. (Watershed data source: NHDPlus Version 2 (EPA 2012). Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community.)

Watershed Vulnerability Assessment Framework

A watershed is an area of land that drains all the streams and rainfall to a common outlet such as the outflow of a reservoir, mouth of a bay, or any point along a stream channel (USGS 2016). In this assessment, we take a holistic approach to assess the climate change vulnerability of watersheds in the Uinta-Wasatch-Cache and Ashley National Forests (fig. 4). This assessment synthesizes available information on how climate change may affect hydrologic function, disturbance regimes, and aquatic,



riparian, and upland vegetation species. In addition, human influences that affect watersheds undergoing climate change are considered, as well as management activities that may alleviate stressors and climate change effects.

Current scientific literature and expert elicitation is used to provide evidence for vulnerability rankings of watersheds. The vulnerability approach is based on the Northeastern Association of Fish and Wildlife Agencies framework (NEAFWA) (Manomet 2012). This framework has been applied in Massachusetts (Manomet 2010), 14 northeastern States (Manomet 2012), the Badlands National Park in South Dakota (Amberg et al. 2012), and the Gunnison Basin in Colorado (Neely et al. 2011). In this application, we have modified the original NEAFWA model such that seven criteria are used to assess watershed vulnerability to climate change and current stressors for the



Figure 4—Watersheds on the Uinta-Wasatch-Cache National Forest (photo: Brendan Waterman, Uinta-Wasatch-Cache National Forest).

mid-21st century (table 1). These 7 criteria were used from the original NEAFWA vulnerability model that has 11 climate criteria, but were combined here to group similar topics of vulnerability.

This watershed approach allows for an efficient means to assess vulnerability across a range of resources that are managed. It also provides an initial overview of available information. Scientific studies conducted in these forests are incorporated when available. When such local information is unavailable, studies are used from the Rocky Mountain, western United States, or other areas with similar ecologic and hydrologic characteristics. Vulnerability assertions are contingent on the available information and we reveal where knowledge gaps exist. National Forest land manager input was used to organize information in a manner that relates to informing management activities. For example, we draw on the Forest Service Watershed Condition Framework, which classifies watershed condition as “the state of the physical and biological characteristics and processes within a watershed that affect the soil and hydrologic functions supporting aquatic ecosystems” (USDA 2011 p. 3). Expert elicitation from university experts, Forest Service researchers, and National Forest staff is used to vet the scientific literature summarizing factors of vulnerability and offer expert input on vulnerability rankings.

Seven criteria define different factors of vulnerability to climate change and non-climate stressors (table 1). Vulnerability is scored in five categories: Very Low, Low, Moderate, High, or Very High for each of the seven vulnerability criteria. The final vulnerability ranking is determined by averaging the score categories of the seven criteria into a final score. This assessment describes vulnerability of the Wasatch Range and the Uinta Mountains separately with separate vulnerability summaries and scores included for the Wasatch Range and Uinta Mountains, and, where appropriate, by lower, middle, and upper elevations.

Table 1—Criteria and associated rationale used to establish watershed vulnerability to climate change. For each criteria, the vulnerability was assigned a score of very low, low, moderate, or high or very high vulnerability.

1. Range shift capacity

The elevation range shift potential of plants and animals is likely to have a complex response to temperature warming with environmental factors as well as climate, causing irregular range shifts. This criterion accounts for whether upslope area exists to make range shifts possible under climate change. Potential restriction to these shifts (other than fragmentation defined below) are defined in other criteria of this assessment.

- Plants and animals living at high elevations (for example, the alpine life zone or near peak tops) are likely to have a very high vulnerability to climate change because upslope migration is simply not a possibility.
- Middle elevation plants and animals have a high, moderate, or low vulnerability because some degree of upslope area exists for biota to migrate and extend their range upslope, assuming environmental conditions and a means to migrate allow for an upslope range expansion.
- Low elevation plants and animals have a very low vulnerability because they have the most available land to extend their ranges upslope, assuming environmental conditions and a means to migrate allow for an upslope range expansion.

Fragmentation or factors inhibiting range shift capacity:

- Plants or animals that are constrained by fragmentation of stream networks or habitats in watershed landscapes (for example, fish that are confined by barriers) are less able to track changes in climate and have a very high vulnerability to a changing climate.
- Plants or animals that have some fragmentation constraining their range movement have a high, moderate or low vulnerability assigned.
- Plants or animals that are not constrained by fragmentation, and that can keep pace with changes in climate (for example, consistent seedling success into new areas or invertebrate movement by flying), are comparatively free to shift across stream networks, and Watershed landscapes are less likely to be vulnerable to a changing climate. A very low vulnerability is assigned.

2. Vulnerability of cold-adapted, foundation, or keystone species to climate change

- Cold-adapted species are those that have adaptive mechanisms to tolerate cold environments and are sensitive to warm temperatures. These species are differentiated from warm-adapted species that tolerate warm to hot temperatures.
- Foundation species are those that have substantial influences on ecosystem structure and function as a consequence of their high biomass.
- Keystone species are those that exert strong effects on the structure and function of their ecosystem, despite having a low biomass.

Vulnerability is assigned based on the degree of species' sensitivity to exposure of a warmer and drier climate and their ability to adapt and persist.

- A very high vulnerability is assigned if species have a high risk of being eliminated from watersheds.
- A high, moderate, to low vulnerability is assigned if species are likely to be hampered to a high, moderate or low degree, but not eliminated.
- Very low vulnerability is assigned if species are not hampered and have a high likelihood of persisting or expanding.

3. Sensitivity to extreme climatic events (drought, heat, floods)

- Sensitivity is the degree to which watershed function that influences species' habitats is affected by changes in climate such as droughts, floods, and extreme heat.
- Very high sensitivity is assigned when higher frequencies or severities of extreme events raise the risk to greatly disrupt watershed function.
- A high, moderate, or low sensitivity is assigned when higher frequencies or severities of extreme events raise the risk to disrupt watershed function to a high, moderate, or low degree.

- Very low sensitivity is assigned when increased frequency or severity of extreme events is unlikely to significantly affect watershed function.

4. Intrinsic adaptive capacity to climate change

- Intrinsic adaptive capacity is the inherent ability of watersheds to accommodate or cope with climate change impacts.
- Very high vulnerability is assigned when adaptive capacity mechanisms are low. Watersheds have impaired function and are heavily affected by stressors, thus contributing to a low adaptive capacity.
- A high, moderate, or low adaptive capacity is assigned when a high, moderate, or low degree of impaired function affects watersheds' adaptive capacity.
- Very low vulnerability is assigned when adaptive capacity is high for watersheds that are least affected by stressors. Unimpaired function of hydrology and vegetation increases the ability to adapt to climate change.

5. Dependence on a specific hydrologic regime

- The hydrologic regime is the characteristic pattern of water flowing through an ecosystem, and it is dependent on climate to determine the rate, timing, and volume in groundwater and surface water moving through streams, lakes, reservoirs, and wetlands.
- Very high vulnerability is assigned when watershed function is within a relatively narrow hydrologic regime. For example, snow-driven aquatic ecosystems (with hydrologic processes and cold-adapted biotas like fish) that are highly dependent on stream flow from snowmelt have a high vulnerability.
- High, moderate, or low vulnerability is assigned when watersheds are less dependent on a narrow hydrologic regime. Hydrologic processes and biota can withstand some variability. For example, vegetation depends on moisture during the growing season but is not dependent on a specific form and can withstand annual variation or periods of drought.
- Very low vulnerability is assigned when watersheds are not dependent on a narrow hydrologic regime. Hydrologic processes and biota are not dependent on a specific form or timing of moisture. An example of this would be an ecosystem that can withstand periods of little to no moisture along with periods of elevated moisture.

6. Potential for climate change to exacerbate effects of non-climate stressors, or vice versa

Climate change effects of warming and drying can exacerbate or worsen non-climate stressors. For example, human water withdrawals (a potential stressor) lower water levels in streams and lakes, and climate warming can increase evaporation, further lowering water levels.

- Very high vulnerability is assigned when there is a high probability that climate change may worsen the effects of a non-climate stressor, or that the non-climate stressor may worsen the effects of climate change.
- High, moderate, or low vulnerability is assigned when there is some probability that climate change may worsen the effects of a non-climate stressor, or that the non-climate stressor may worsen the effects of climate change.

Very low vulnerability is assigned when there is a very low probability that climate change may worsen the effects of a non-climate stressor, or that the non-climate stressor may worsen the effects of climate change.

7. Likelihood of managing or alleviating climate change effects

- Watersheds have very high vulnerability when there are no known feasible management approaches that could be employed. The likelihood of effectiveness is very low to mitigate the effects of climate change and reduce non-climate stressors.
- Watersheds have a high, moderate, or low vulnerability when feasible management approaches exist and have been shown to have high, moderate, or low effectiveness in mitigating the effects of climate change and reducing non-climate stressors.
- Watersheds have a very low vulnerability when feasible management approaches exist and have been shown to be very effective in mitigating the effects of climate change and reducing non-climate stressors.

Climate of the Uinta-Wasatch-Cache and Ashley National Forests, Utah

Observed Climate

The Uinta-Wasatch-Cache and Ashley NFs encompass some of the wettest terrain in Utah. That, combined with high elevation and cooler temperatures, has historically permitted large snowpacks to accumulate in winter and melt in the spring and summer, acting as Utah's largest reservoir (fig. 5). This snowmelt provides water to the State's population centers when demand for water is high due to landscape and agriculture irrigation. Additional human-made reservoirs and groundwater help meet demand in the late summer and fall when snowmelt-driven streamflows generally recede.

Temperature

Temperatures have increased throughout Utah, as well as the western United States, over the past century and most rapidly since 1970. Utah's Climate Division 5 (fig. 6) encompasses the majority of Uinta-Wasatch-Cache and Ashley NFs as well as adjacent lands outside of the forest boundary in northeastern Utah. The average annual temperature in this area has risen since 1970 (fig. 7).

Precipitation

The precipitation record in Utah and Climate Division 5 is dominated by large inter-annual and decadal variability. No long-term trends have yet been observed in seasonal or annual precipitation in northern Utah (fig. 8).

Snow

Studies of the western United States have indicated a tendency toward decreasing snow water equivalent (SWE), also known as earlier snowmelt peak and runoff, most notably in coastal and lower elevation areas (Mote 2006; Mote et al. 2005; Regonda et al. 2005). Warming temperatures have led to more winter precipitation falling as rain instead of snow in Utah. Gillies et al. (2012) documented a 9 percent decrease in the proportion of winter precipitation (January–March) falling as snow from 1950 to 2010 in Utah, a combined result from a significant increase in rainfall and a minor decrease in snowfall. They also reported a decrease in snow depth across Utah, accompanied by consistent decreases in snow cover and decreases in surface albedo. Julander and Clayton (2014) identify 19 ongoing reference snow course sites across Utah, which they deemed appropriate for long-term SWE studies because they are not compromised by site characteristics, most notably vegetation encroachment. None of these snow courses show significant increasing trends in April 1 SWE, but only 16 percent (3 of the 19 reference sites in southcentral and southeastern Utah) show statistically significant downward trends in April 1 SWE over their respective periods of record varying from 60 to 85 years.

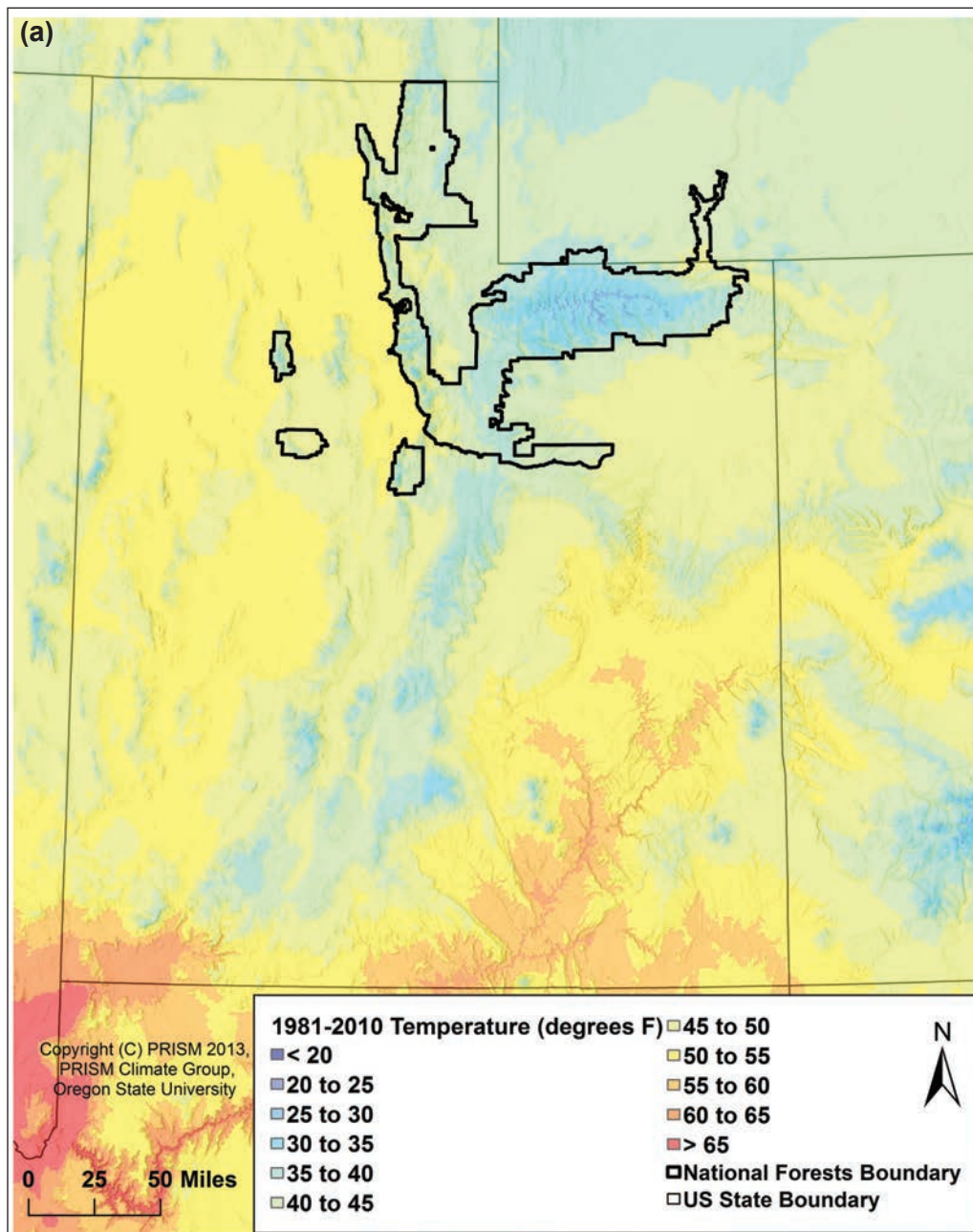
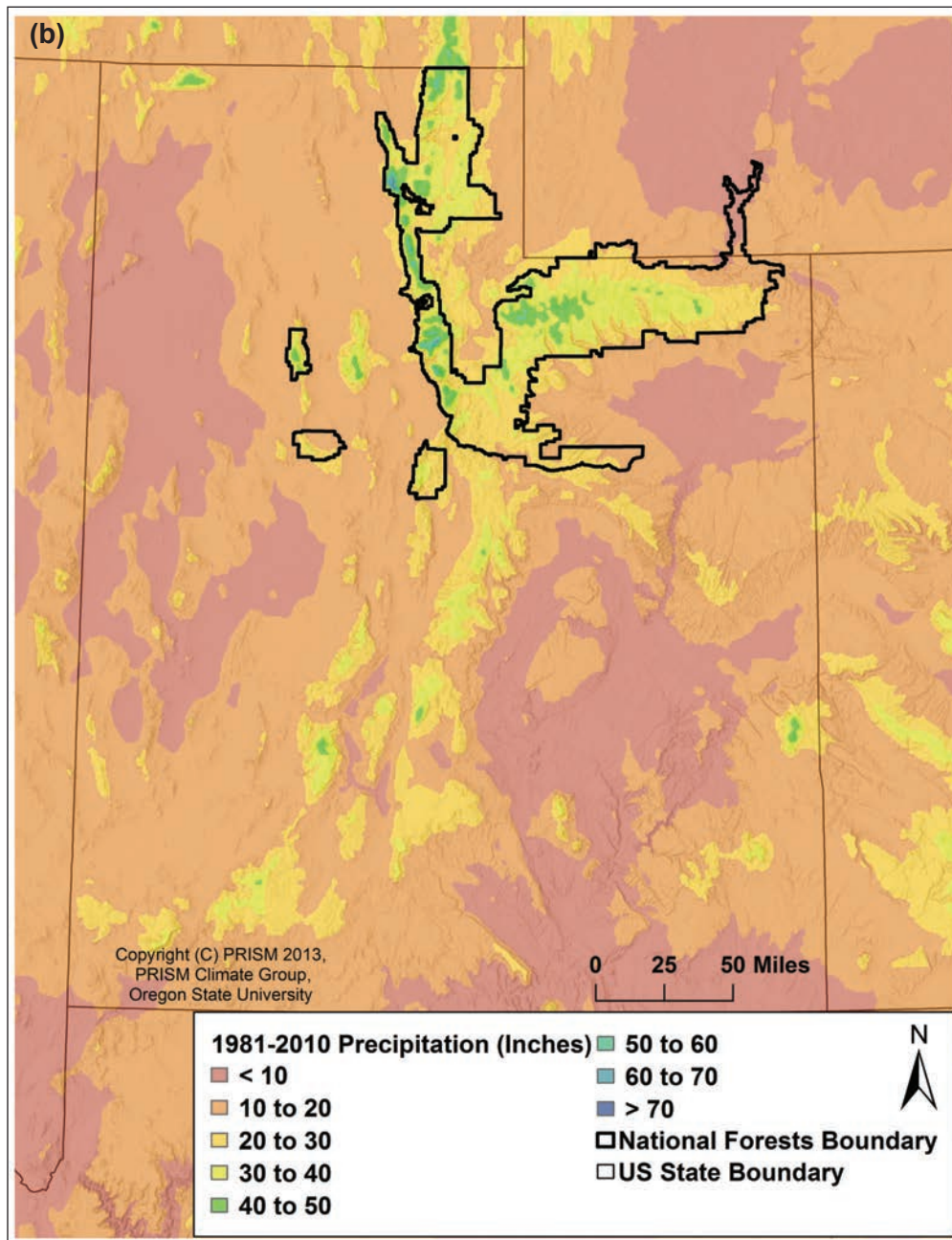


Figure 5—Annual mean temperature (°F) (a) and total annual precipitation (inches) (b) for 1981–2010 over the State of Utah based on observed climate and spatially interpolated using the Parameter-Elevation Relationships on Independent Slopes (PRISM) model. The resolution is at 800 meters. (Copyright © 2016, PRISM Climate Group, Oregon State University, <http://prism.oregonstate.edu>. Map created March 1, 2016. Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap, and the GIS user community.)



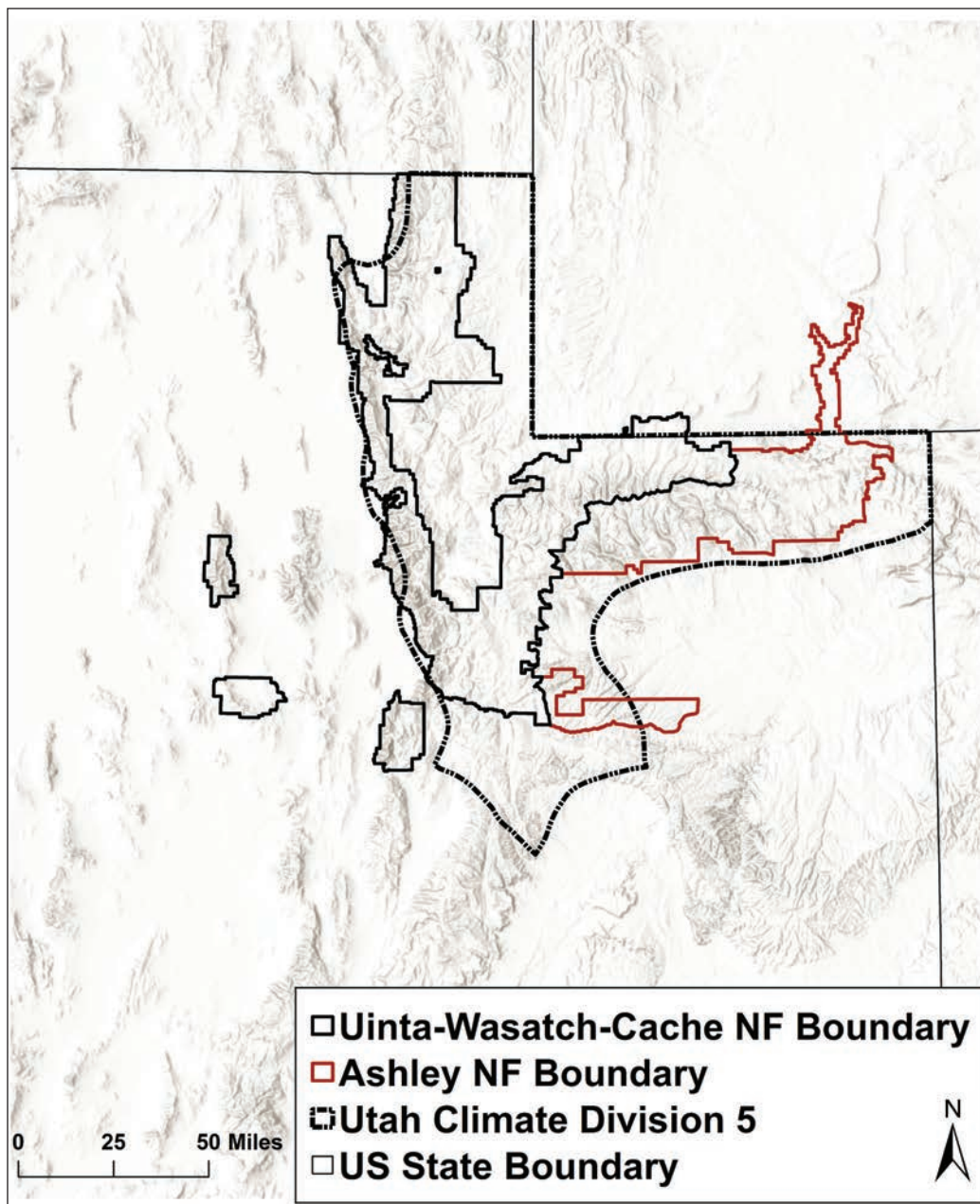


Figure 6—Utah’s Climate Division 5 overlaid on the Uinta-Wasatch-Cache and Ashley National Forests Boundaries. (Source: NOAA Climate Division GIS data, <http://www.ncdc.noaa.gov/monitoring-references/maps/us-climate-divisions.php>. Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community.)

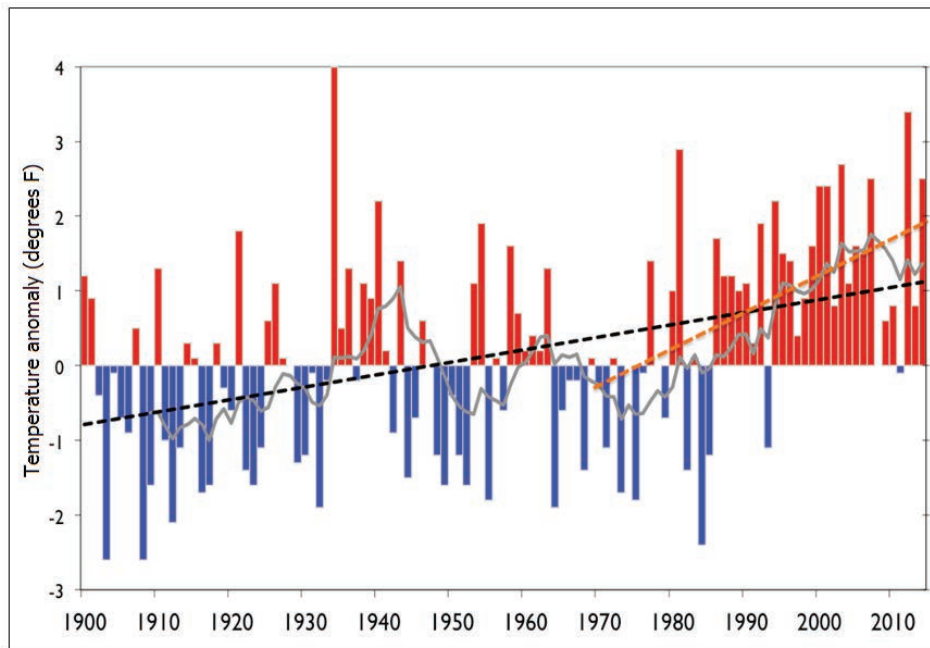


Figure 7—Utah Climate Division 5 temperature anomaly of the mean annual temperature (°F), 1900–2014. Annual departures are relative to the 1901–2000 average. The dashed black line and orange lines are the 1900–2014 and 1970–2014 linear trends, respectively. Both upward trends are statistically significant. The average annual temperature in Climate Division 5 has risen over the last century with a statistically significant trend of 0.2 °F/decade since 1900, and 0.5 °F/decade since 1970 (Mann-Kendal p value <0.01). The gray line is the 10-year running average. Utah Climate Division 5 encompasses the majority of the Uinta-Wasatch-Cache and Ashley National Forests (data source: NOAA, <http://www.ncdc.noaa.gov/cag/>).

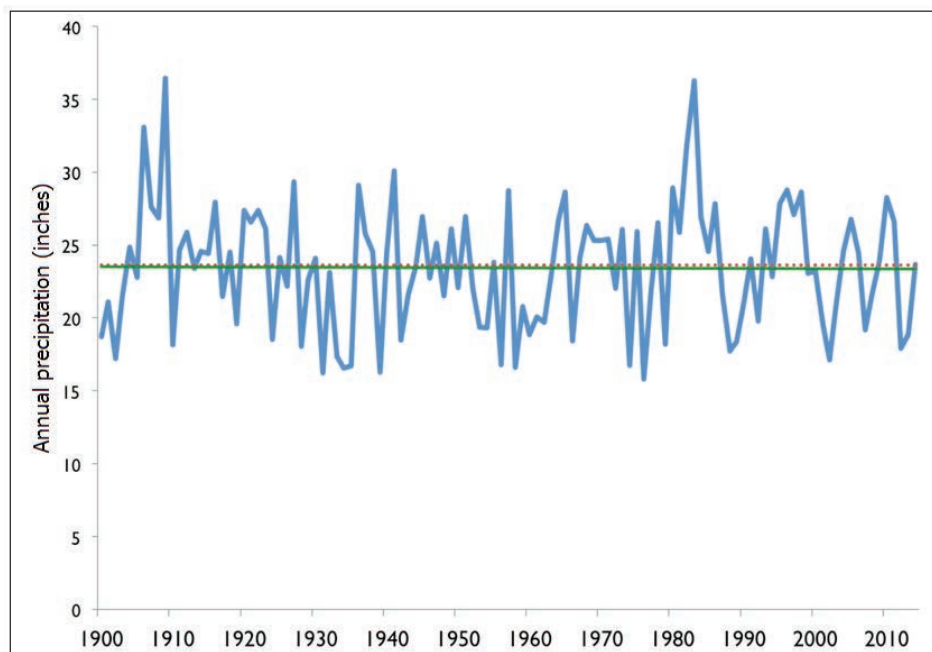


Figure 8—Utah Climate Division 5 average annual precipitation (inches) 1900–2014. The dashed red line is the 1901–2000 average, and the green line is the 1900–2014 linear trend, both of which show no trend (data source: NOAA, <http://www.ncdc.noaa.gov/cag/>).

Projected Changes in Climate

Global Climate Models (GCMs) are quantitative tools used to explore the range of possible future climate conditions. GCMs simulate the complex interactions among the land, oceans, and atmosphere, and they are based on fundamental scientific principals using advanced mathematics in computationally intensive simulations. These climate model outputs have a range of projections from different trajectories of future greenhouse gas concentrations. Representative Concentration Pathways (RCPs) are four greenhouse gas (GHG) concentration trajectories over the 21st century that are used by climate models in the 5th assessment report of the Intergovernmental Panel on Climate Change (IPCC) (<http://www.ipcc.ch/report/ar5/>). The four pathways are RCP 2.6, RCP 4.5, RCP 6, and RCP 8.5. The first pathway has the lowest forcing (the cumulative measure of human emissions of greenhouse gases) RCP 2.6, and assumes that global annual GHG emissions peak between 2010–2020, and then decline. GHG emissions in RCP 4.5 peak around the year 2040 and then decline. In RCP 6, GHG emissions peak around 2080 and then decline. RCP 8.5 has the largest forcing, where emissions continue to rise throughout the 21st century.

The Coupled Model Intercomparison Project Phase 5 (CMIP5) uses the four standardized greenhouse gas concentration scenarios or RCPs. This project was established by the Working Group on Coupled Modeling (WGCM) to provide a standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models (AOGCMs) (see Appendix C table C1 for list of models). While each climate modeling center uses fundamental physical principles to drive their models, some climate processes are represented differently in each model. Consequently, future simulations of temperature and especially precipitations vary among different models.

While GCMs have advanced significantly in the past several decades to include additional processes and higher spatial resolution, even the highest resolution existing GCMs cannot adequately represent the steep mountainous terrain of the Uinta Mountains and Wasatch Range. A variety of downscaling methods have been developed to translate GCM output to scales capturing the terrain variability relevant to resource managers. In this study, we utilized the Bias-Correction Spatial Disaggregation (BCSD) method (Maurer et al. 2007) to represent the mountainous terrain of the Uinta Mountains and Wasatch Range (data available at <http://gdo-dcp.ucllnl.org>).

Downscaled temperature and precipitation climate projections in Utah's Climate Division 5 for the middle-low forcing climate scenario RCP 4.5 show an average of 3.7 °F increase in annual temperature, and on average, a small annual precipitation increase by mid-century compared to a 1981–2010 baseline (table 2, figs. 9 and 10) (downscaling technique by Maurer et al. [2007]). See Appendix A, figs. A1–A6 for the full range of climate forcing scenarios projections. Nighttime low temperatures are expected to rise as much as daytime high temperatures. Projections indicate that summer temperatures may warm somewhat more than winter and spring (fig. 9). While there is a high degree of confidence that temperatures in all seasons will continue to increase, there is less confidence with projected changes in precipitation. The RCP 4.5 projections on average indicate about a 4 percent increase in annual precipitation, but about one-third of the 71 model runs indicate decreases in future mean annual precipitation.

Table 2— Projected changes in mean annual temperature and precipitation from 1981–2010 to 2035–2064 for northeastern Utah Climate Division 5 under RCP 4.5.

Projected changes by 2035–2064 ^a	Mean	10th ^b	50th ^c	90th ^d
Change in mean annual temperature (°F)	3.7	2.2	3.7	4.9
Change in mean annual precipitation (%)	4.2	-5.8	3.2	15.1

^a Projections are based on 71 model runs from 1/8° CMIP5 BCSD (bias-correction and spatial disaggregation) for the Representative Concentration Pathway (RCP) 4.5. Accessed from: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html.

^b The 10th percentile value has 10 percent of model outputs that are less than or equal to the value, while 90 percent are above the value.

^c The 50th percentile value has 50 percent of the model outputs less than or equal to the value, while 50 percent are above the value.

^d The 90th percentile value has 90 percent of the model outputs less than or equal to the value, while 10 percent are above the value.

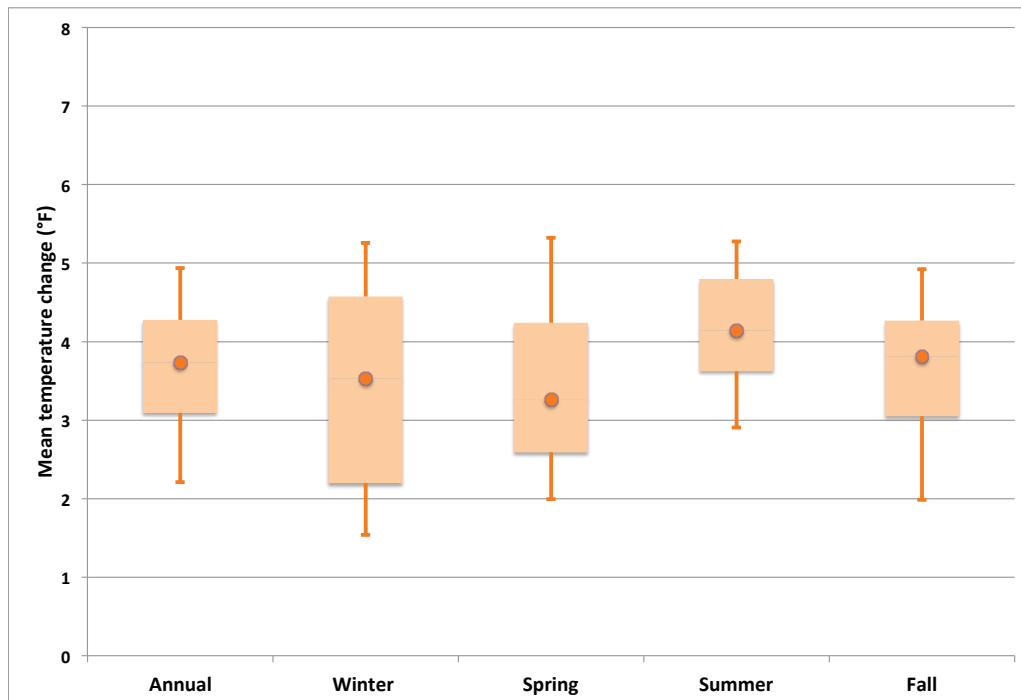


Figure 9—Annual and seasonal projected change in temperature for Climate Division 5 2035–2064 relative to 1981–2010 for 71 model runs from the RCP 4.5 of the Climate Model Intercomparison Project phase 5 (CMIP5). Dots represent the average change, while the whiskers represent the 10th and 90th percentiles, and the boxes represent the 25th and 75th percentiles of the 71 model runs. (See Appendix A for projections of RCP 2.6, RCP 6.0, and RCP 8.5. Reclamation 2014.)

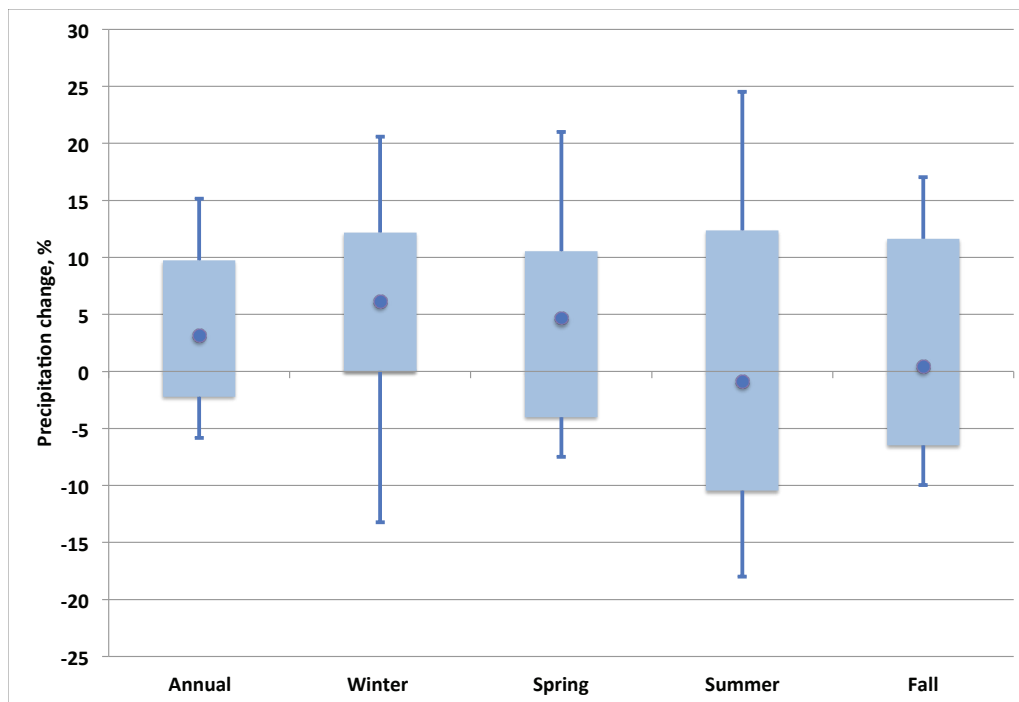


Figure 10—Annual and seasonal projected change in precipitation for 2035–2064 relative to 1981–2010 from 71 model runs from the RCP 4.5 of the Climate Model Intercomparison Project phase 5 (CMIP5 Appendix D). Dots represent the average change, while the whiskers represent the 10th and 90th percentiles, and the boxes represent the 25th and 75th percentiles of all model runs. (See Appendix B for projections of RCP 2.6, RCP 6.0, and RCP 8.5. (Reclamation 2014).

There is higher model run agreement that winters will be wetter, with 75 percent of model runs indicating an increase in average winter precipitation. However, the uncertainty in precipitation projections is of particular concern in mountainous areas, so these increased precipitation projections must be taken with that in mind. Historical declines in precipitation at high elevations across the Pacific Northwest have been associated with decreasing wind speeds and orographic enhancement (Luce et al. 2013). This historical trend has been missed because there are fewer precipitation gages at high elevations. The gages are used in model calibration; hence the models may have a wet bias. This uncertainty increases the importance of understanding trends in historical precipitation (this section) and in historical streamflow (see “Dependence on Specific Hydrologic Regime” section).

In figure 11, the 10th percentile (+2.2 °F) and 90th percentile (+4.9 °F) of the projected temperature increases for RCP 4.5 were uniformly added to the PRISM 1981–2010 observed mean temperatures. Under the 90th percentile warming, annual mean temperatures at upper elevations in the Uinta Mountains (plus 4.9 °F) are raised to just below or above freezing levels, while the majority of upper elevation areas in the Wasatch Range are raised above freezing.

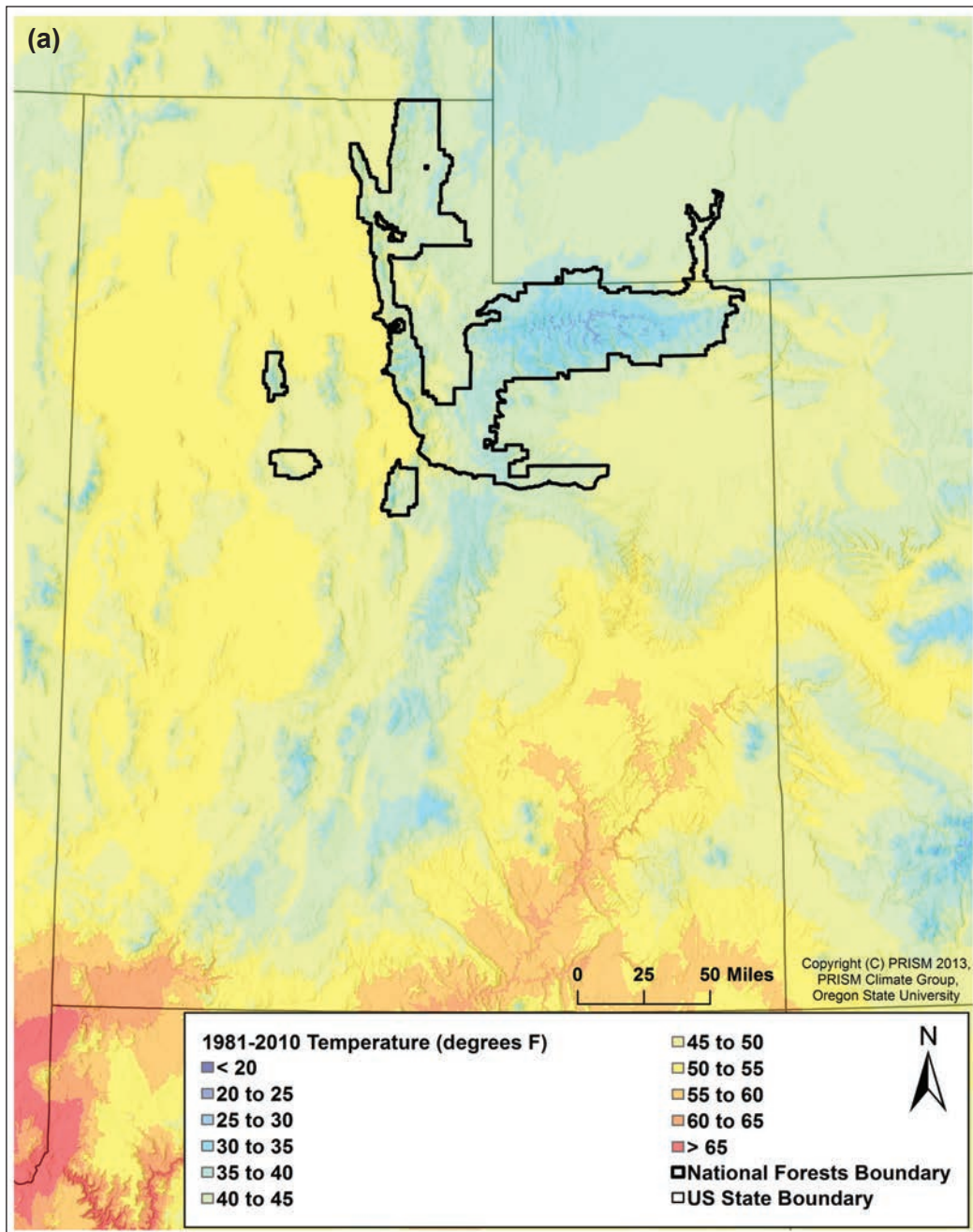
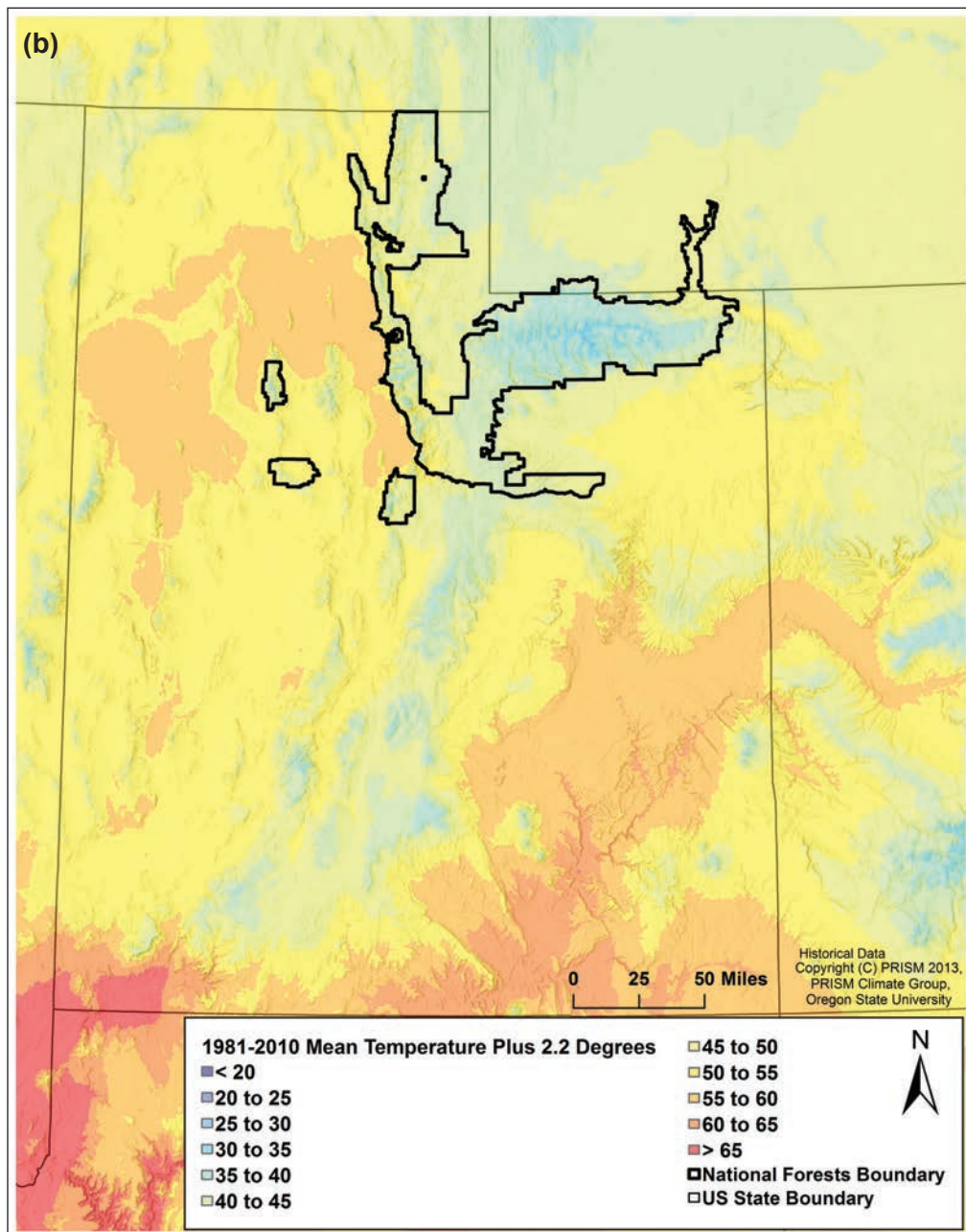
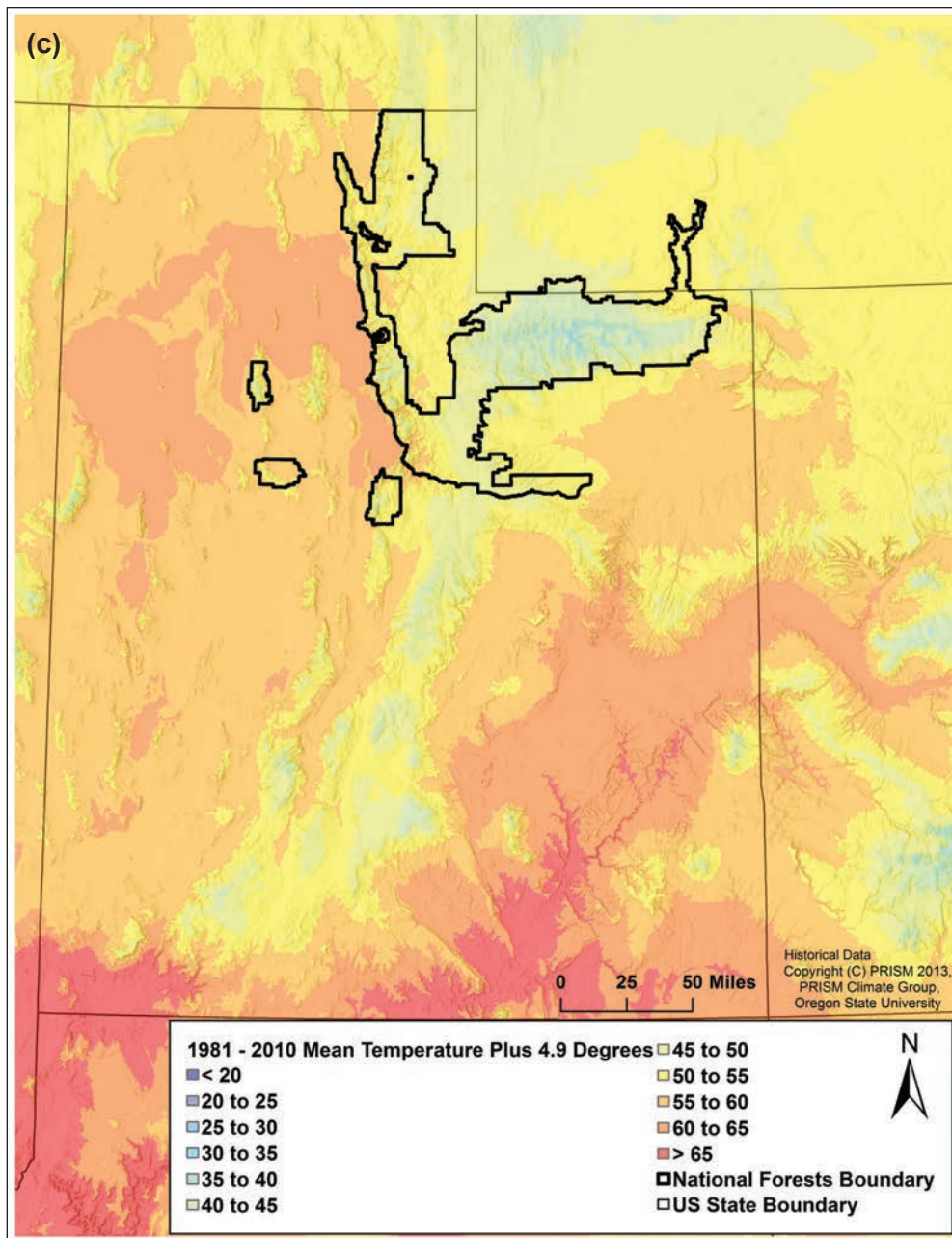


Figure 11—Mean 1981–2010 PRISM temperatures (a); mean 1981–2010 temperature plus 2.2 °F (b); and mean 1981–2010 temperature plus 4.9 °F (c). (Historical Data Copyright © 2016, PRISM Climate Group, Oregon State University, <http://prism.oregon-state.edu>. Map created March 1, 2016. Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap, and the GIS user community.)



Temperature increases across the different slope gradients of the Wasatch Range and Uinta Mountains are likely to be variable, with different degrees of warming associated with topography. Loarie et al. (2009) modeled that as temperatures increase over time, flatter areas would have more area experiencing temperature increases than steeper areas. This climate velocity concept was used by Isaak and Rieman (20013) to model isotherm shifts in mountain streams of central Idaho. An isotherm is a line on a map or chart of the earth's surface connecting points having the same temperature at a given time. They projected that with a 0.2 to 0.4 °F temperature increase per decade, steep streams (2–10 percent slope) had isotherms shift at 0.13 to 1.3 km per decade, while flat streams (<1 percent slope) had isotherms shift across more area at 1.3 to 25 km per decade. These modeling results indicate that with warming temperatures over time, flat stream slopes may have more area sensitive to temperature warming than streams on steep slopes.



Projected Trends for Snow

As temperatures rise, more rainfall and less snow are expected in the Uinta Mountains and Wasatch Range (fig. 12). Klos et al. (2014) projected that by mid-century, a large portion of the Wasatch Range will receive more than 50 percent of December to February precipitation in the form of rain. The majority of the Uinta Mountains has more than 90 percent of precipitation falling as snow in both the historic and mid-century 2035 to 2065 time periods. The decrease in the moisture received as snow would result in less snowpack and drier soil moisture during the growing season.

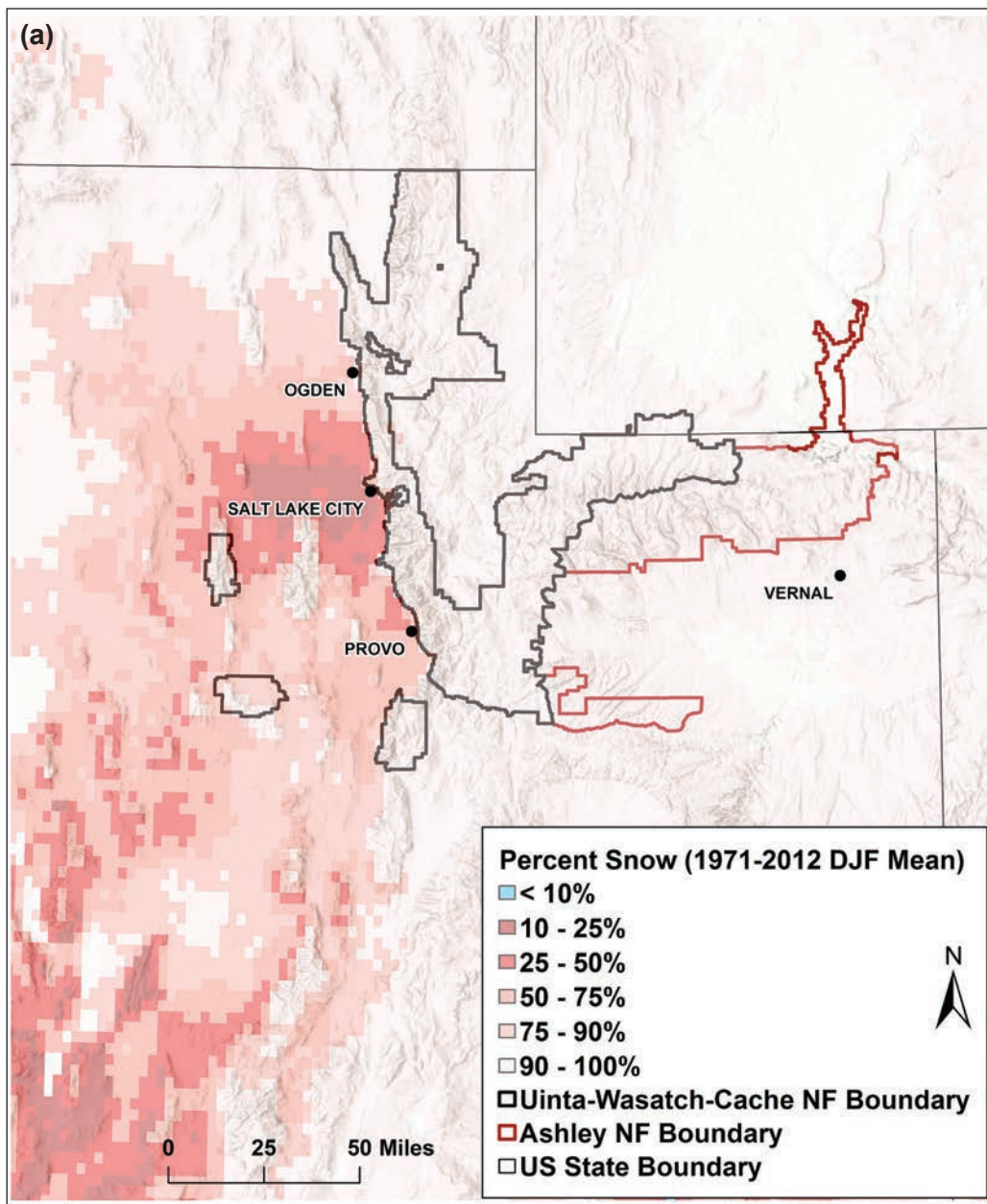
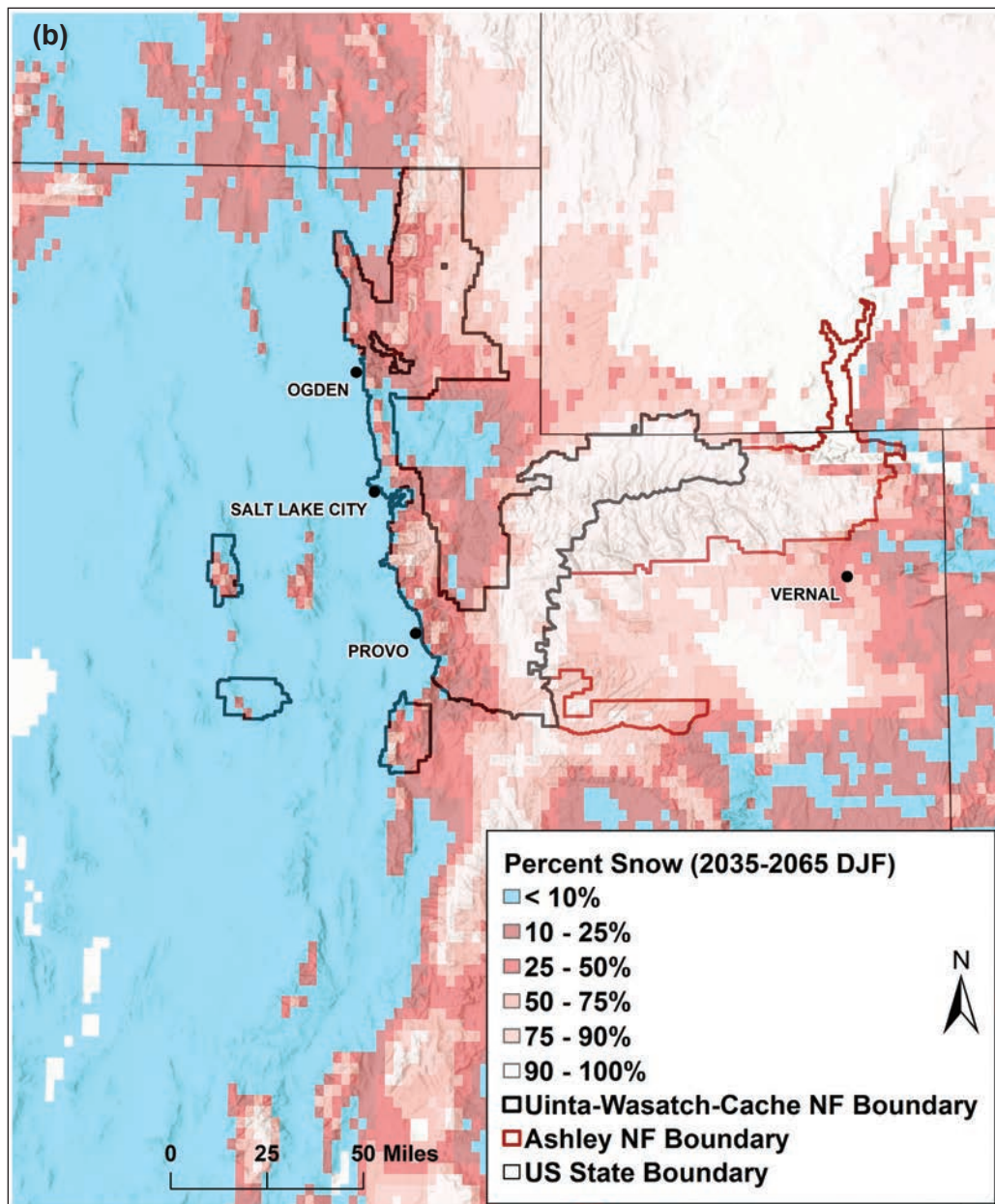


Figure 12—Percent of total precipitation received as snow, monthly mean for the months of December, January, and February. Modeled for historic (1979–2012) (a) and mid-century (2035–2065) (b) using the high emissions scenario (RCP8.5) and averaged over 20 CMIP5 climate models (Klos and et al. 2014). Note: Areas in light gray to white in southwestern Wyoming are where precipitation was excluded from model runs since the amounts were below a minimum threshold. (Data available at: http://zionklos.com/rain-snow_maps/. Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community.)



Warmer temperatures, in the absence of changes in precipitation, are expected to lead to earlier runoff and average annual runoff volume will decrease due to increases in evapotranspiration. A recent study in the Wasatch and western Uinta Mountains have modeled a shift in timing of the center of runoff, the date when half of the water year runoff has occurred, by approximately 3 days earlier per 1 °F warming. In the same study, the average modeled decrease in annual volume was approximately 4 percent per 1 °F (Bardsley et al. 2013). Changes in runoff timing are expected regardless of potential changes in future precipitation and have implications to ecosystems and water management, while changes in annual volume caused by increasing temperatures could be offset by increasing precipitation.

Extreme Events

Relatively infrequent extreme events often exert a disproportionate impact on species and ecosystems. Recent periodic droughts during the 1930s, 1950s, late 1970s, late 1980s, and 2000s have been much less severe or persistent than many droughts in previous centuries. Prolonged drought periods lasting several decades, or mega droughts as reconstructed from tree rings, occurred during the 1200s, late 1400s, and 1800s (Bekker et al. 2014; DeRose et al. 2015; MacDonald and Tingstad 2007). MacDonald and Tingstad (2007) reported 19 episodes of single-year or multiyear extreme droughts over the last 500 years. Severe and extreme intensity droughts were recurrent events in the Uinta Mountain region averaging two to five times per century since the 1400s (MacDonald and Tingstad 2007). Bekker et al. (2014) found that most Wasatch Range droughts were during the 1400s and 1500s, while the 1700s and 1800s had fewer but the longest duration droughts. Three severe droughts were during the 1930s, the late 1950s, and early 2000s. In both the Uinta Mountains and Wasatch Range, the 1900s was a relatively wet period compared to previous centuries, with the least recurrence of drought (Bekker et al. 2014; MacDonald and Tingstad 2007). The recent drought events in the Wasatch Range and Uinta Mountains have been correlated with periods of decreased eastern Pacific sea surface temperatures (Kunkel et al. 2013; MacDonald and Tingstad 2007). Recent drought as measured by the Palmer Drought Severity Index has increased in Utah's Climate Division 5 since 1970, due mostly to increasing temperatures driving more rapid drying.

There is high climate model agreement that more extreme heat will occur by the mid-21st century. Kunkel et al. (2013) projections show an increase of 5 to 10 days per year where temperatures exceed 95 °F in northern Utah. The largest number of projected extreme heat days is in lower elevations around the Uinta Mountains and Wasatch Range (see fig. 23 in Kunkel et al. 2013). Multiple-day periods of extreme high temperatures are expected to increase as the climate warms (Lukas et al. 2014). Extreme heat events have been increasing over the past 30 years, but the number of events occurring from 2003 to 2012 did not exceed the amount experienced during the 1930s (Lukas et al. 2014).

Fewer storm events with more precipitation per event have been happening in Utah since the mid-20th century (Gillies et al. 2012). Bekker et al. (2014) found that extremely wet periods, or pluvials, during the 17th century were wetter than the early 1900s pluvial, but was dwarfed compared to the 1980s flood event in the Wasatch Front. A climate reconstruction for the Bear River in the Wasatch Range based on tree ring records by DeRose et al. (2015) found that the latter half of the 20th century was the second wettest in 1,200 years. High flows in the Uinta Mountains were also recorded between the late 16th to mid-17th century and the first half of the 20th century (Carson and Munroe 2005). Extreme peak flow events have been increasing in the Uinta Mountains since the 1960s as a result of high precipitation and cold winter and early spring temperatures that preserve snowpack (Carson 2007). Kunkel et al. (2013) report no observed increase in days with precipitation exceeding 1 inch from 1980 to 2000 on the southwestern United States, but projections show the number of greater than 1 inch precipitation days to increase by the end of the 21st century for northern Utah. Extreme precipitation events and extreme heat are projected to increase for the region by the end of the 21st century across the United States, while consecutive dry days are projected to also increase (Kunkel et al. 2013; Wuebbles et al. 2014). These projections would tend to lead to enhanced risk of both flood and drought in a warmer future climate.

Vulnerability of Uinta-Wasatch-Cache and Ashley National Forests Watersheds to Climate Change

Range Shift Capacity

Wasatch Range Vulnerability: High	Uinta Mountains Vulnerability: Moderate
<p>Elevation range shifts: Vulnerability spans from very low to very high across the Wasatch Range depending on elevation location that extends from around 5,000 to 11,000 feet. The majority of land area is in the foothills life zone below 8,000 feet elevation.</p> <ul style="list-style-type: none"> High to very high vulnerability is assigned where plants and animals exist near peak tops, where they have the least area available for expansion into cooler areas should unsuitably warm and dry conditions develop. Moderate vulnerability is assigned for plants and animals in the montane life zone and mid-elevation as they have more potential area available for upslope expansion. Low to very low vulnerability is assigned where foothills life zone and low-elevation plants and animals exist, since they have the largest amount of upslope area available. Upslope range expansion assumes suitable environmental conditions exist for biota to move into upslope, which may not always be the case. 	<p>Elevation range shifts: Vulnerability spans from very low to very high across the Uinta Mountains depending on elevation location that extends from about 6,000 to 13,000 feet. The majority of land area is in the montane and subalpine life zones between 8,000 to 11,500 feet elevation.</p> <ul style="list-style-type: none"> High to very high vulnerability is assigned where upslope range expansion is most limited in the alpine and other life zones where biota exist near peak tops. Moderate vulnerability is assigned for subalpine, montane life zone, and mid-elevation biota as there is upslope area available. Low to very low vulnerability is assigned for foothills life zone and low-elevation biota that have the most potential area for upslope expansion. Upslope range expansion assumes suitable environmental conditions exist for biota to move into upslope, which may not always be the case.
<p>Fragmentation: High vulnerability</p> <ul style="list-style-type: none"> Given that headwater streams in the subalpine life zone are inherently fragmented, further warming and drying of these aquatic habitats will affect aquatic organisms. A high vulnerability is assigned. The structural barriers from water diversions, dams, and steep slopes are especially common along the Wasatch Front. Fragmentation from human land uses may be more pronounced in the lower elevation foothill and montane life zones. High vulnerability is assigned. Plants and animals will have varying responses to habitat fragmentation. Insects or amphibians may be moderately affected since habitat fragmentation may already exist and become more so in the future. But animals that are mobile can move to new areas that offer suitable habitat. Plant range movement can lag behind climate and may be hindered by fragmentation of site conditions or unsuitable soils, and thus have a moderate to high vulnerability. 	<p>Fragmentation: Moderate vulnerability</p> <ul style="list-style-type: none"> Stream fragmentation from warming and drying may be a factor along the elevational ranges, but in the upper Colorado Basin, climate-related stream fragmentation is not modeled to be a critical factor for native cold-water fish. A moderate vulnerability is assigned. Physical barriers (water diversions and dams) fragment streams in the Uinta Mountains, although they are less common in the high-elevation wilderness areas, but natural barriers can fragment streams in wilderness areas. Moderate vulnerability is assigned. The effect of habitat fragmentation on plants and animals in the Uinta Mountains is assumed to be similar to the Wasatch Range with a moderate to high vulnerability assigned (see summary to left).
<p>Summary of literature information depth supporting vulnerability</p> <ul style="list-style-type: none"> Range shift potential is supported by four studies. These studies focus on vegetation. Fragmentation affecting fish is supported by 10 studies; macroinvertebrates, 1 study; and amphibians, 1 study. These studies cover areas on or near the Uinta and Wasatch Mountain Ranges. Fragmentation affecting vegetation is supported by eight studies, and several caveats on migration are included. 	

Elevational Range Shift Capacity of Watershed Biota

The potential for upslope migration of plants and animals is a function of the available area and the suitability of environmental conditions. Peak elevations of Uinta watersheds extend to over 13,000 feet and the majority of area is at high elevations between 8,000 and 11,500 feet (fig. 13). In contrast, the Wasatch Range elevations extend to almost 12,000 feet, but the majority of watershed area is at mid- and low elevations between 5,000 and 8,000 feet elevation (fig. 13). Streams reach up to almost 12,000 feet in the Uintas and extend to almost 11,000 feet in the Wasatch Range.

Species living along the several thousand feet span of elevations in the Uinta Mountains and Wasatch Range have different vulnerabilities, depending on suitable upslope area available for migration and the ability of the species to migrate. Upslope elevation shifts with range contractions of plants are projected across the Rocky Mountains. For example, warming and drying is projected to result in an upslope expansion and lower elevation range reduction of vegetation (Hansen and Phillips 2015; Notaro et al. 2012). Riparian plant species and ecotypes are expected to shift upstream (Perry et al. 2012). High-elevation alpine biota have a high vulnerability as they have little to no area or habitats available for them to migrate upslope to escape hotter

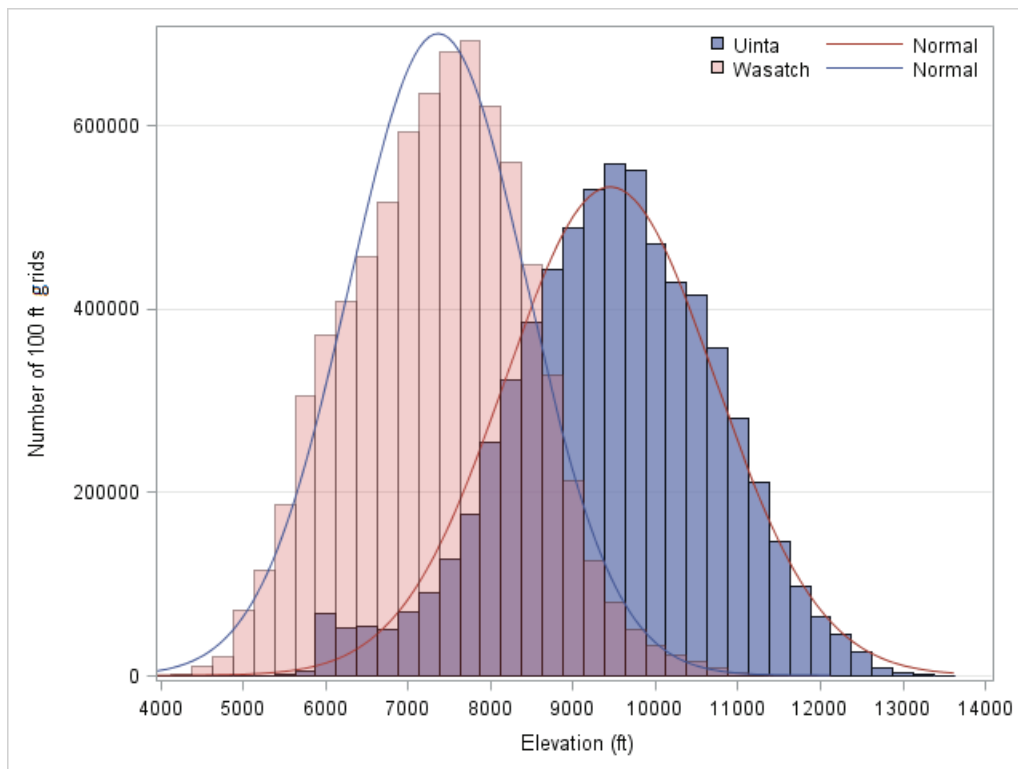


Figure 13—Elevation distribution histograms of total area for the Wasatch Range in pink (that includes the Stansbury Mountains) and overlaid with the Uinta Mountains in blue-gray (excluding the Flaming Gorge Reservoir in Wyoming). The purple bars are the result of overlapping transparent colors in the Wasatch and Uinta elevation distributions. Normal distribution curve lines are in gray for the Wasatch Range and red for the Uinta Mountains. Elevation distributions are derived from an approximately 100 feet (30 m) resolution (Digital Elevation Model data source: USGS 2014).

climates (fig. 14). In forested areas below peak tops, some upslope area is available for migration. Gray and Hamann (2013) projected lodgepole pine would shift 238 feet upslope by 2050 in the Rocky Mountains. Plants living in areas well below peak tops, or in the montane or foothills life zone, are less vulnerable as upslope area is available for migration assuming plant migration is possible. The upslope migration of subalpine trees is being seen in some areas of the Uinta Mountains (Allen Huber, Ashley National Forest, Vernal, UT, personal communication, 2015).

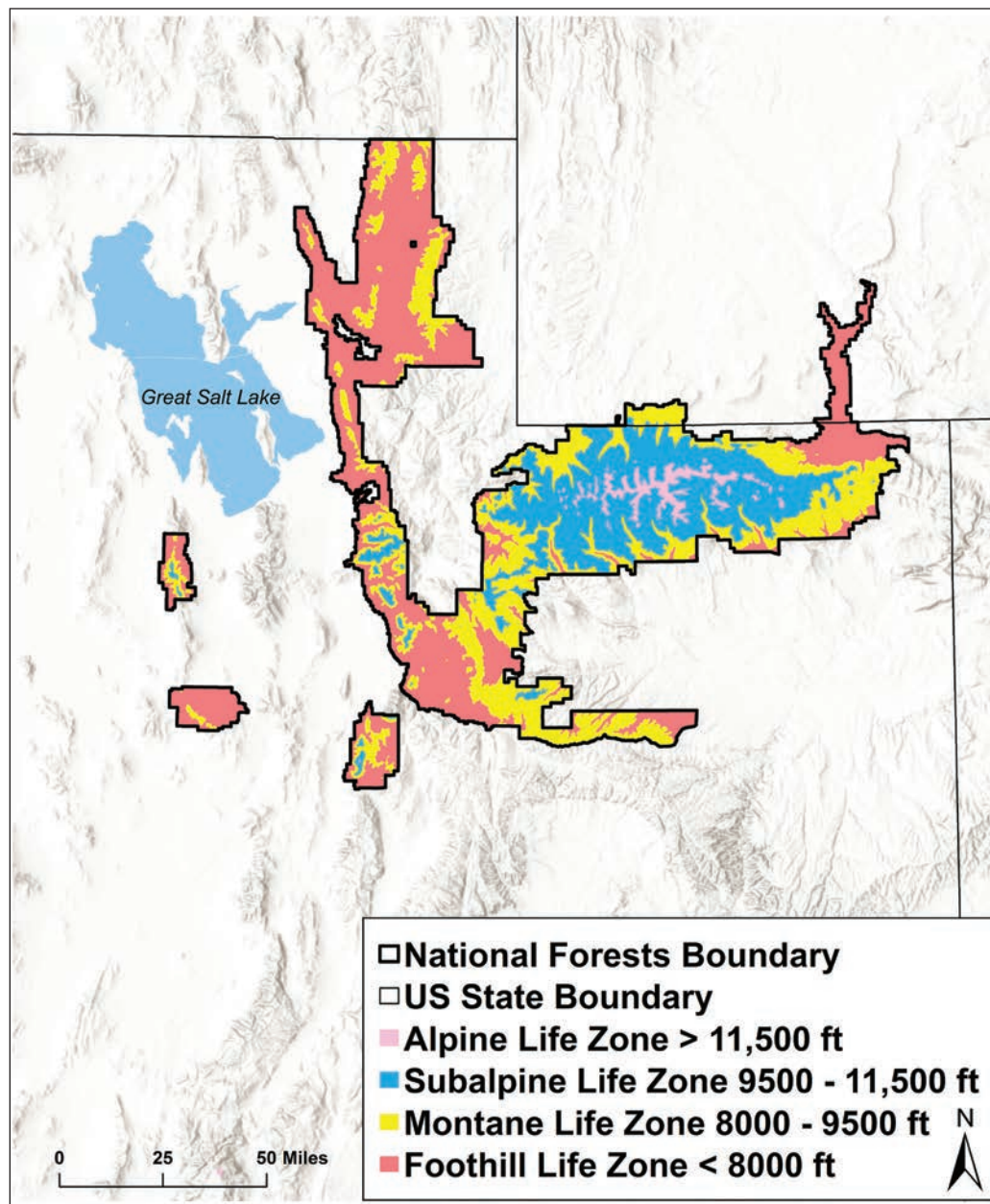


Figure 14—Alpine, Subalpine, Montane and Foothill Life Zones across the Wasatch Range and Uinta Mountains. Life zone categories derived from Utah Division of Wildlife Resources (UDOWR 2002). (Elevation data source: USGS 2014). Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community.)

In summary, both the Wasatch Range and Uinta Mountains have vulnerability spanning from low in the foothills life zone, to moderate in the montane and subalpine life zones, to high or very high for species at peak tops or in the alpine zone, given that warmer temperatures make habitats unsuitable for current biota. These potential range shifts depend on several environmental factors further discussed in the next section.

Fragmentation Inhibiting Range Shift Capacity

Fragmentation Affecting Stream Habitat and Aquatic Species

Fragmentation of plant and animal species habitats can be a factor inhibiting migration across stream networks or across watersheds. Aquatic environments in the Uinta Mountains and Wasatch Range are hydrologically connected by both surface water and groundwater. While groundwater flow is connected and controlled by precipitation inputs, soils, and vegetation type (Burke and Kasahara 2011), surface water habitat can easily become fragmented by unsuitable thermal conditions, or by structural barriers, or by lack of streamflow (Fagan 2002; Isaak et al. 2010). Warmer temperatures during summer may isolate stream sections that cold-water fish occupy (Roberts et al. 2013), and fish escaping heat in lower elevation streams move into cooler headwater streams. Streams in alpine or subalpine areas are more isolated and thermally unsuitable habitat may develop downstream, cutting off the high-elevation streams from other tributaries in the drainage network, as was observed in southeastern Wyoming (Rahel et al. 1996) and the Columbia River Basin (Rieman et al. 2007). In addition to warmer than average stream temperatures, lower than average streamflow, or no streamflow during summer or during drought periods, further fragment and reduce the amount of stream habitat available to fish, as was observed in the southwestern United States (Jaeger et al. 2014).

Besides climate factors, natural and human-made physical barriers can fragment streams and restrict the movement of fish. There are hundreds of dams and thousands of water diversions on Uinta-Wasatch-Cache and Ashley NF streams (UDOWR 2014b), although they are less common in the wilderness areas. Structures block fish movement unless fish passage structures are in place. Waterfalls and steep stream gradients were also found to divide streams and restrict fish passage in Wyoming, Colorado, and New Mexico (Harig and Fausch 2002; Kruse et al. 1997). Native trout were not found to reside in streams with gradients greater than 10 percent in the Absaroka Mountains, Wyoming (Kruse et al. 1997). Isaak et al. (2015) reported that fish occupancy in the northwestern United States was less than 1 percent in streams that have more than 15 percent gradient.

Colorado River cutthroat trout with less than 2.5 miles (4 km) of connected stream habitat were projected to have a low probability of persistence under a warmer future climate with stochastic disturbance and weather events (Roberts et al. 2013). The trout were projected to have a high probability of persistence when more than 4.4 of connected stream miles (7 km) were available (Roberts et al. 2013). For the Uinta Mountain portion of this study in the Upper Colorado River Basin, these headwater regions had a low extirpation risk for the trout as stream fragmentation and stream temperature warming were not critically inhibiting factors for the trout in the future.

Aquatic species that can move by land or air also are affected by fragmentation and may require different mechanisms to adapt to the different environments into which they may migrate. For example, macroinvertebrates adapted to warmer climates are likely to expand into areas that cold-adapted species can no longer tolerate, but warm-adapted species that burrow may not adapt to the higher-erosion environments of upper elevations (Poff et al. 2010). Another example is amphibians that can disperse across landscapes but require connected habitats for population viability (Cushman 2006).

Fragmentation Affecting Vegetation

In general, results from bioclimatic envelope and dynamic global vegetation models (DGVMs) analyses point to a northward and upslope expansion of lower-elevation plants and losses of plant species at higher elevations over the 21st century (Bachelet et al. 2001; Hansen and Phillips 2015; Notaro et al. 2012). Notaro et al. (2012) projected that the mountains of Utah, including the Wasatch Range, would see evergreen tree die-off associated with drier and warmer climate, and grass growth would be favored at lower elevations. At the highest elevations of the Uinta Mountains, however, evergreen tree cover was projected to expand in response to warming (Notaro et al. 2012). Great Basin shrub-grasslands and desert scrub were projected to shift toward suitable climates developing upslope, replacing the montane conifer forests by the late 21st century in the Wasatch Range and Uinta Mountains (Hansen and Phillips 2015). Subalpine and montane conifers were projected to find suitable climates in the alpine areas by the late 21st century (see fig. 2 in Hansen and Phillips 2015). Range expansion of plant species may occur in unexpected directions in some cases, as Shafer et al. (2001) projected unexpected southward shifts of oak from the Pacific Northwest into the Great Basin as a result of warmer and drier conditions, complex topography, and steep environmental gradients.

Bioclimatic envelope models and DGVMs capture different aspects of plant communities and ecosystem dynamics as they respond to climate change. Notaro et al. (2012) concluded that each modeling approach has its own advantages in assessing the impacts of climate change on regional vegetation. The DGVMs can analyze the potential impacts of increased atmospheric carbon dioxide on water use efficiency; the bioclimatic models they used did not. Thus, bioclimatic models might miss the plant's ability to use water more efficiently with increased carbon dioxide and remain in place even under a drier climate. In contrast, the bioclimatic models used by Notaro et al. (2012) had a range expansion restriction on migration, thus preventing excessive plant migration rates; the DGVMs did not have this feature. Bioclimatic envelope models project changes in species while DGVMs model plant function types, or groups of species, that give the bioclimatic envelope model the ability to assess changes in plant species richness. Also, both types of vegetation models may not always capture the effect of fine-scale processes and fragmentation in the landscape that could lower the range shifting capacity of some plant communities. For example, soil structures and steep slopes may hinder and prevent grass or shrub communities from moving into areas where suitable climates exist (fig. 15).



Figure 15—Sheep Creek area on the Spanish Fork Ranger District in the Uinta-Wasatch-Cache National Forest. Soils formed from the Green River Formation (shale) have the consistency of beach sand with no structure, and as a result of the steep slope, the sand is being deposited over grass (photo: Stacey Weems).

Although vegetation range shifts are a likely response to climate warming, as model projections show, there are some cases that this may not always be possible, even in areas where environmental conditions, climate, and low fragmentation would otherwise accommodate movement. Topography, soils, and geology may not support vegetation types that move from other areas or lower elevations (Macias-Fauria and Johnson 2013; Perry et al. 2012). Also, plants migrating to new areas may not keep up with the rate of climate change. Gray and Hamann (2013) projected tree range shifts upslope, but tree range movement lagged over 400 feet behind the movement of their optimal climate by 2020. Migration may be further delayed by competition with resident species (Corlett and Westcott 2013). Invasive species may also play a role in inhibiting plant communities (see discussion on “Climate Change and Invasive or Non-Native Species”).

In summary, fragmentation from unsuitable thermal conditions, low streamflows, or natural and man-made barriers is especially hindering to fish, while species that can move by air or land are less affected. The Wasatch Range has a high amount of fragmentation from land uses, and a high vulnerability is likely from more fragmentation as a result of future temperature warming. The Uinta Mountains are less affected by land use fragmentation and likely have a moderate vulnerability. Plant range shifts in both the Wasatch Range and the Uinta Mountains may not always be inhibited by fragmentation, but sometimes topography, soils, geology, or invasive species may inhibit range movement. Thus, fish have a high vulnerability, while plants and animals would likely have a moderate to high vulnerability depending on the degree of fragmentation that could hinder range movements. The degree of fragmentation varies across watersheds with more fragmentation potentially restricting plant and animal movement, giving them a high vulnerability in those cases.

Vulnerability of Cold-Adapted, Foundation, or Keystone Species to Climate Change

Summary	
Wasatch Range vulnerability: Spans from low to very high	Uinta Mountain vulnerability: Spans from low to very high
<ul style="list-style-type: none"> • Trout and native cold-water fish have a vulnerability assigned that spans from high at low elevations to moderate or low vulnerability for upper elevations of the Wasatch Range. Most of these fish live in lower elevation foothills life zone streams (<8,000 feet elevation) where they may be exposed to wildfire, drought, winter flooding, variable or lower streamflows, and stream temperature warming that exceeds fish tolerances. Fish in the headwater stream networks (>8,000 feet elevation) may experience less exposure to climate stresses, but headwater stream habitats offer limited fish habitat with shorter and more fragmented streams. 	<ul style="list-style-type: none"> • Trout and native cold-water fish have a low to moderate vulnerability assigned for the Uinta Mountains as most fish live in montane and subalpine life zone streams (>8,000 feet elevation), which have a lower risk for wildfire, flooding, drought, variable or low streamflow, and summer temperature warming that exceeds fish tolerances. Low-elevation streams in the Uinta Mountain foothills life zone may experience more exposure to drought, wildfire, and summer temperature warming. Fish may find climate refugia at higher elevations of the Uinta Mountains that offer relatively unfragmented stream habitats.
<ul style="list-style-type: none"> • Amphibians in the Wasatch Range have a very high vulnerability assigned as climate warming; drying greatly hampers them, and these effects can be compounded by disease, habitat loss, and predation. Larger water bodies may serve as refugia against warming and drying. 	<ul style="list-style-type: none"> • Amphibians in the Uinta Mountains will likely have a very high vulnerability as in the Wasatch Range (see summary to left).
<ul style="list-style-type: none"> • Macroinvertebrates have vulnerabilities assigned that span from low to high. High vulnerability is assigned for cold-adapted species or ones that tolerate a narrow temperature range. Low to moderate vulnerability is assigned to lower elevation, warm-adapted species as they tolerate warmer conditions and may benefit from warming. The warm-adapted species are vulnerable to reductions in streamflows, however. These warm-adapted species may expand to higher elevations if suitable thermal conditions develop there, but some species may not be able to adapt to the steeper or more erosive higher-elevation mountain environments, in which case they would have a high vulnerability. 	<ul style="list-style-type: none"> • Macroinvertebrates in the Uinta Mountains are likely to have the same vulnerability (spanning low to high) as the Wasatch Range (see summary to left). There is little information to differentiate macroinvertebrate vulnerability between the Wasatch and Uinta Mountains other than the Uinta Mountains having more area above the montane life zone than the Wasatch Range, which may offer more area for species occupation at these higher elevations.
<ul style="list-style-type: none"> • Beaver are likely to persist and be moderately vulnerable to climate change. They could be hampered by more variation in flows, flooding, or warming and drought that reduces vegetation and lowers water inputs. 	<ul style="list-style-type: none"> • Beaver in the Uinta Mountains will likely have moderate vulnerability as in the Wasatch Range (see summary to left).

<ul style="list-style-type: none"> • Riparian vegetation in the Wasatch Range is assigned vulnerability spanning from low to high. Lower elevation riparian vegetation in the foothills life zone likely have a high vulnerability since plants are susceptible to stresses from drying, warming, snowpack loss, and human land uses. Upper elevation vegetation above the montane life zone are also subject to some drying, warming, and snowpack loss, but human influences are less, which lowers the vulnerability. 	<ul style="list-style-type: none"> • Riparian vegetation in the Uinta Mountains will likely have similar vulnerability as the Wasatch Range (see summary to left). The Uintas may experience less warming, drying, and snowpack loss than the Wasatch Range, but these areas will be subject to some degree of warming, drying, and snowpack loss that would affect riparian plants.
<ul style="list-style-type: none"> • Upland vegetation in the Wasatch Range, which is commonly aspen, oak, and maple, will likely have vulnerability spanning from low at lower elevations to very high at upper elevations, with an overall contraction of forest conifers projected by late century as the climate warms. Exceptions to these general climate-driven vulnerabilities of species exist as they respond dynamically to complex environmental factors in addition to climate change. 	<ul style="list-style-type: none"> • Upland vegetation in the Uinta Mountains is likely to have very high vulnerability in the alpine life zone and low vulnerability in lower elevations, with conifers that dominate these mountains projected to contract by late century as they are replaced by lower elevation plants (see summary to left).
<p>Summary of literature information depth supporting vulnerability:</p> <ul style="list-style-type: none"> • A large literature collection (19 studies) supports factors of climate vulnerability for fish. The literature is less broad regarding how climate change may affect amphibians (10 studies), macroinvertebrates (11 studies, some highly cited), beavers (11 studies), upland vegetation (7 studies), and riparian vegetation (6 studies). • Plasticity of plant species undergoing climate change is an area needing further study. Four studies are cited here. • Much of the literature is outside the Forests, although Rocky Mountain studies are included, which have similar ecosystems. 	

A set of species tied to watershed hydrology and function is selected to capture different ranges of biotic functions and environmental tolerances. Native cold-water and non-native fish are selected since these species include important game fish, and the cold-water natives are sensitive indicators of climate change. Amphibians and macroinvertebrates are selected as they are both a food source for fish. Macroinvertebrates also perform important aquatic functions of breaking down organic material. Beaver are a keystone species that can beneficially affect hydrologic function and other organisms in watersheds. Riparian and upland vegetation are selected as they are foundation species that can regulate flows, provide habitat and food for biota, and reduce erosion in watersheds.

Trout and Native Cold-Water Fish

The mountain streams of the Uinta Mountains (fig. 16) and Wasatch Range support a variety of fish. For many species, little information about their sensitivity to environmental variability and climate exists. Here, we summarize the available literature on non-native trout (brook, brown, and rainbow) and two species of cutthroat trout and the mountain whitefish.



Figure 16—Stream habitat in the Uinta Mountains (photo: Mark Muir, Ashley National Forest).

Colorado River and Bonneville cutthroat trout are native cold-water fish species that have experienced large range contractions attributed to the introduction of competing non-native fish and human land uses that have degraded fish habitat in and around the Wasatch Range and Uinta Mountains (Budy et al. 2007; Dauwalter et al. 2011; Horan et al. 2000; McHugh et al. 2008). Future climate is expected to further stress cold-water and non-native fish with warmer stream habitats, lower streamflow, more variability in flow regimes and thermal conditions, reduced and disconnected streams, and larger and more frequent disturbances (Isaak et al. 2010; Jentsch et al. 2007; Rieman and Isaak 2010). The changes in climate can warm stream temperatures beyond tolerance limits for native cold-water fish (Young 2008), and non-native trout (Wenger et al. 2011). Brinkman et al. (2013) found that mountain whitefish have an even lower heat tolerance than cutthroat trout, with a critical thermal maxima (CTM) at 80 °F (Bonneville cutthroat CTM is 82.2 to 83 °F, and Colorado River cutthroat trout CTM is 82.4 to 84.4 °F). These fish will likely have higher sensitivity to warming temperatures than cutthroat trout. Where fires occur, postfire fish populations are further stressed by the reduction in riparian canopy cover that compounds climate effects with warmer stream temperatures (Luce et al. 2012). Recent observed streamflow trends for the Wasatch Range and Uinta Mountains show that most streams have no declining or increasing trend, but three streams—the Duchesne, Ashley, and Weber—have had statistically significant declines over the last 65 or more years (see fig. 28 in the “Dependence on Specific Hydrologic Regime” section). The majority of model studies projects future decreases of streamflow in the Colorado River Basin (Vano et al. 2014), which would reduce stream habitat and stress fish.

Haak et al.'s (2010) evaluation of climate change effects on Bonneville cutthroat trout found that the northern Bonneville Basin covering the central and southern Uinta-Wasatch-Cache NF had high risks that could hamper these trout. Those risks include drought and winter flooding (uncharacteristic flooding resulting from warmer winter temperatures in watershed types of rain-dominated, rain-snow-dominated, or snow-dominated) associated with climate change. Risks also include wildfire for a majority of watersheds. Haak et al. (2010) found that a minority of watersheds in the low elevations of the northern Bonneville Basin had July stream temperatures remaining below 68 °F from 1970 to 2000, but a 5 °F increase resulted in temperatures that exceed the Bonneville cutthroat trout suitable temperature limit used in this study (<72 °F). The mountain watersheds around Bear River and the northwest Uinta Mountains had a majority of the northern Bonneville Basin watersheds with a low risk for summer temperatures that exceed the trout's tolerance levels.

Haak et al. (2010) also assessed Colorado River cutthroat trout. In the higher elevations of the Uinta Mountains there was a low risk of winter flooding, increased summer temperature, drought, and wildfire. Lower elevations, much of which are outside National Forest boundaries, had higher risk for drought, wildfire, and summer temperatures exceeding suitable temperature levels for Colorado River cutthroat below 66 °F.

Wenger et al.'s (2011) western United States regional study projected large range contractions of cutthroat, brook, brown, and rainbow trout associated with warmer temperatures and changes in the flow regime. This study used composite scenarios with an average 4.5 °F temperature increase in the Rocky Mountains and Great Basin. Brook and native cutthroat trout had larger projected range contractions than brown and rainbow trout. The model projected spring-spawning rainbow trout to benefit from changes in winter high flows caused by climate change, while other trout were hindered (Wenger et al. 2011).

Stream temperatures and future warming will vary across elevations, affecting fish differently according to their temperature tolerances. Populations at lower elevations are most susceptible to summer stream temperature warming that most likely will exceed tolerance levels (Haak et al. 2010; Roberts et al. 2013). Warming may improve productivity and growing season length in some high-elevation headwater streams that are currently too cold for native cutthroat trout (Coleman and Fausch 2007; Wenger et al. 2011). In watersheds with small order streams, aquatic habitats could shrink even further and become more prone to disturbance from local weather events so that local population reductions or extirpations become possible (Hilderbrand and Kershner 2000; Roberts et al. 2013).

Isaak et al. (2015) modeled the probability of native cold-water cutthroat trout occupancy in cold stream habitats. They delineated potential refugia for cutthroat trout undergoing the effects of climate change across the northern Rocky Mountains. They mapped the probability of cutthroat trout occurrence for the Bear River Drainage, which covers the northern portion of the Uinta-Wasatch-Cache NF (figs. 17 and 18).

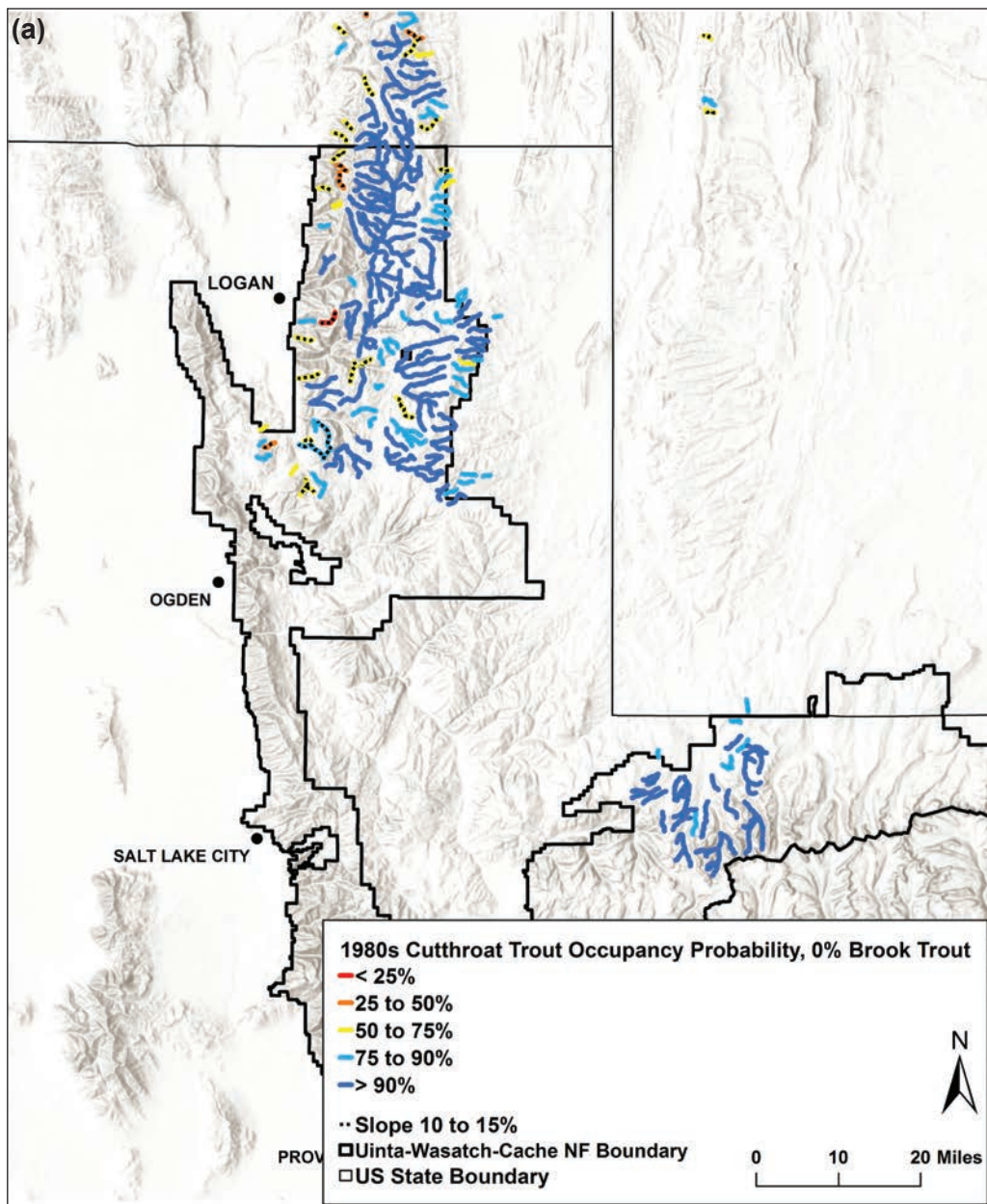
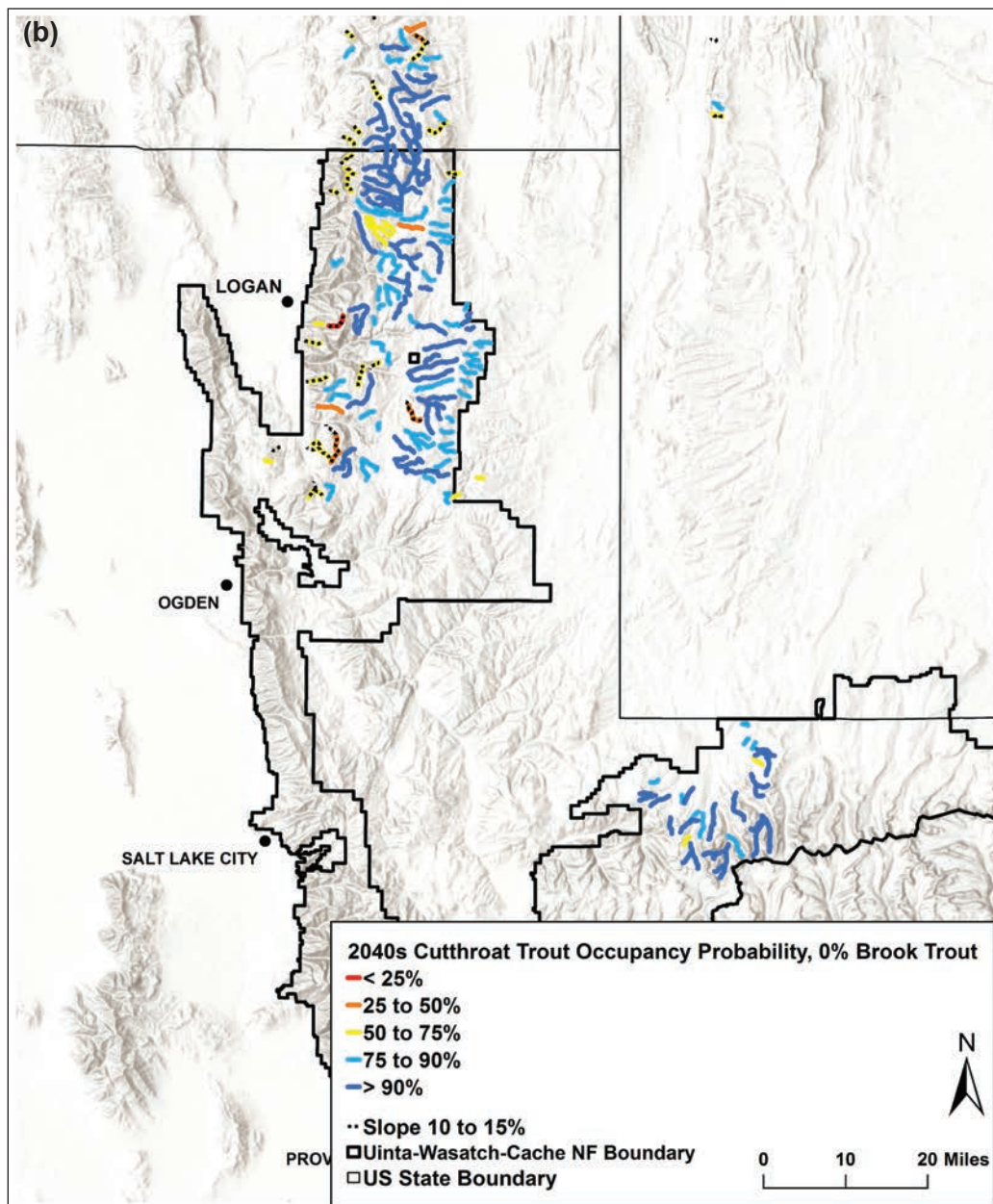


Figure 17—Cutthroat trout occupancy probabilities of streams that have 0% brook trout occupancy. The occupancy probability for 1970–1999 or 1980s (a), and occupancy probability for a projection under a moderate climate scenario that increases stream temperatures 2.3 °F on average by 2030–2059 or 2040s over the Northern Rocky Mountains (b). Streams with dotted lines have slopes between 10 and 15%. (Isaak et al. 2015). (Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community.)



Their analysis using a 2040s climate scenario with 0 percent and 50 percent brook trout presence show a reduction, but not elimination, of potential stream refugia from 1980s levels in which cutthroat trout could occupy (cold-water trout occupancy probability >90 percent). The climate scenarios increase August stream temperatures 2.3 °F (1.3 °C) on average across the northern Rocky Mountains. Their study suggests that warmer temperatures can facilitate upstream movements by rainbow trout and brown trout, but cold headwater streams will continue to serve as important refuges for cold-water fish in many areas, and streams on Forest Service lands may serve as strongholds for native fish (Isaak et al. 2015).

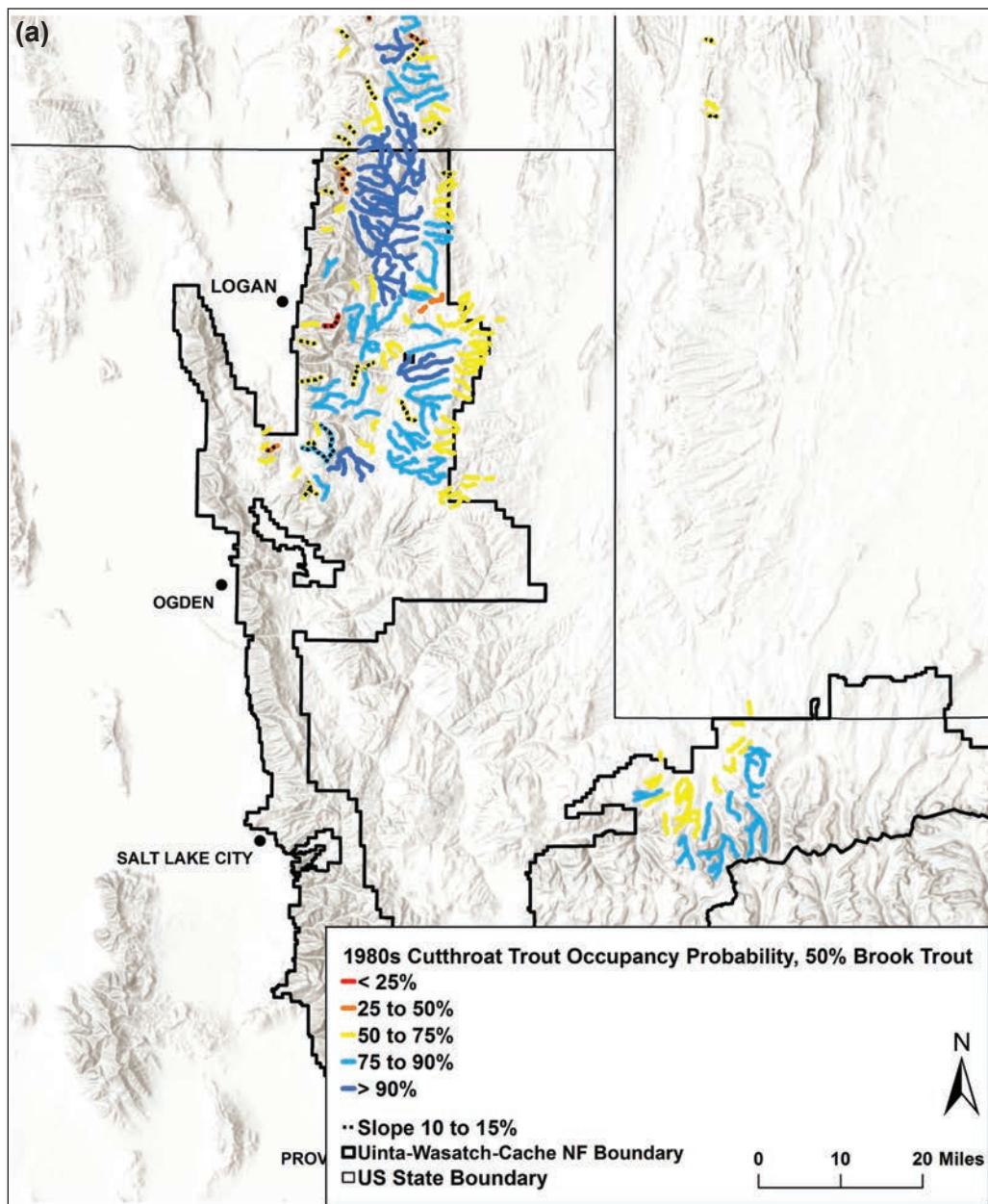
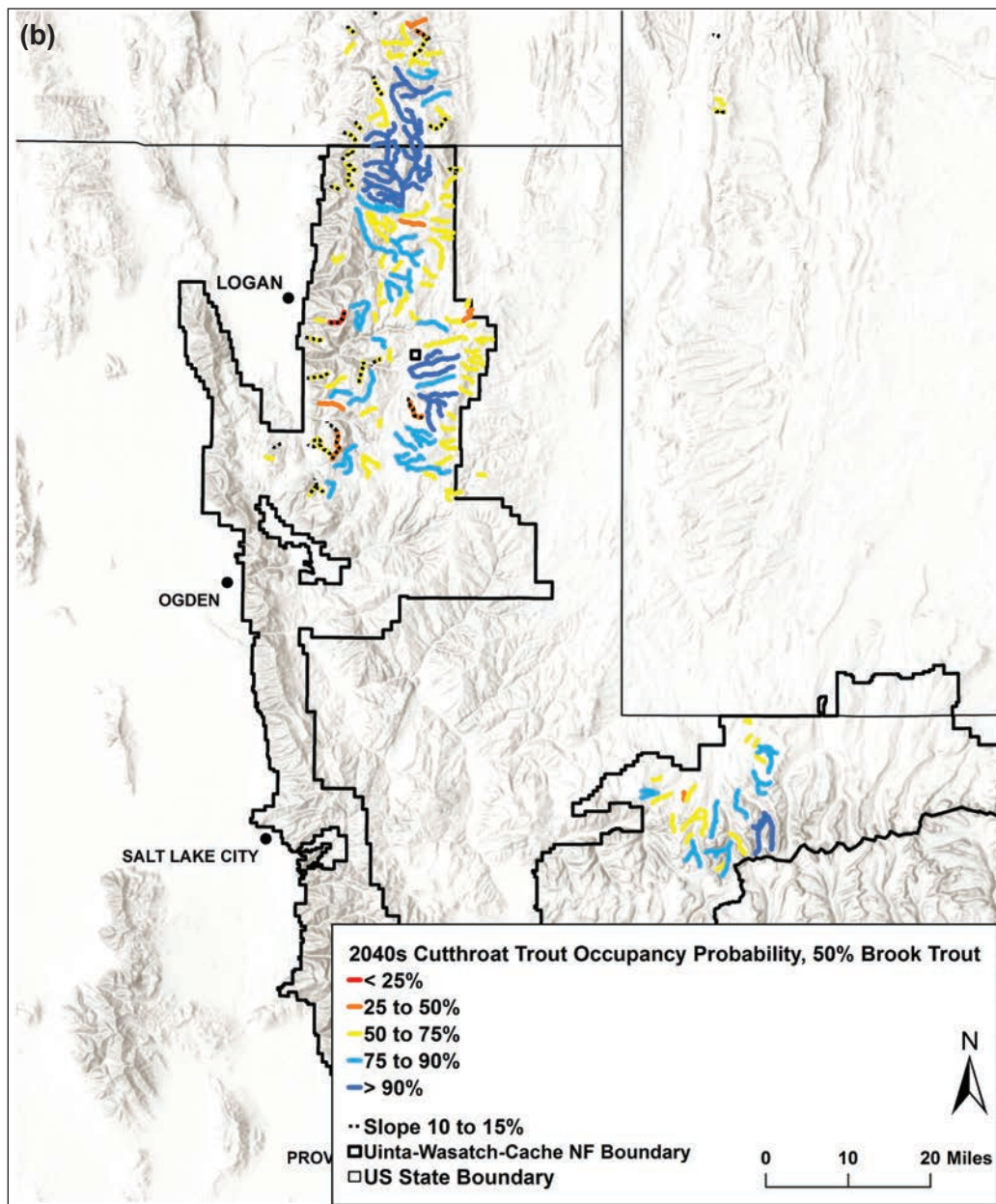


Figure 18—Cutthroat trout occupancy probabilities of streams that have 50% brook trout occupancy. The occupancy probability for 1970–1999 or the 1980s (a), and occupancy probability for a projection under a moderate climate scenario that increases stream temperatures 2.3 °F on average by 2030–2059 or the 2040s over the Northern Rocky Mountains (b). Streams with dotted lines have slopes between 10 and 15%. (Isaak and others 2015). (Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community.)



Across elevations, areas of high productivity are found in low-gradient streams, serving to raise adaptive capacity of fish to climate change. Low-gradient streams are more common in the Uinta Mountains and the northeast Wasatch Range (see “Sensitivity to Floods” section). These flatter gradient streams tend to have more sub-surface water enter and be retained (Chen et al. 2012), benefitting fish habitat. Kozel et al. (1989) found that riffles and pools common in low-gradient streams support larger fish with higher productivity.

Fish living in streams of the Uinta Mountains and Wasatch Range will likely have a higher vulnerability at lower elevations, especially in the Wasatch Range that has more area in the foothills life zone, but a lower vulnerability to climate change at higher elevations. Within the stream networks of these mountains, low-gradient section of streams may serve to enhance productivity and create spatially distinct areas of lower vulnerability along elevation gradients.

For more information on fish vulnerability and methods, see vulnerability assessments and modeling studies in table 3.

Table 3— Fish vulnerability assessments or other analyses providing further information.

*Indicates this study is included in the discussion of this assessment.

Source	Description	Assessment method
Haak et al. (2010)*	Risk assessment of drought, winter flooding, fire, and temperature for inland west salmonids.	Modeling study
Isaak et al. (2015)*	Modeling study projecting likelihood of occupation for cold-water habitats undergoing climate change.	Modeling study
Roberts et al. (2013)*	Modeling study of how fragmentation and climate change affect Colorado River cutthroat trout	Modeling study
Wenger et al. (2010)*	Modeling study of biotic and climate change interactions and how they affect trout distribution	Modeling study
Halofsky et al. (2017)	Bull trout, Westslope, and Yellowstone cutthroat trout vulnerability assessment for the Northern Rockies. Full assessment forthcoming.	Literature synthesis, modeling study, expert elicitation

Amphibians

Toads, frogs, and salamanders are sensitive indicators of environmental change that utilize both aquatic and terrestrial habitats in the Wasatch Range and Uinta Mountains. Species found in these mountains include boreal toad, Great Basin spadefoot toad, boreal chorus frog, northern leopard frog, spotted frog, and tiger salamander. The potential effects of climate change on amphibian species of the Wasatch Range and Uinta Mountains have not been extensively studied, hence we draw from the available literature on species that have similar traits as amphibians found in the assessment area.

The recent decline in amphibian populations in the western United States is attributed to many factors including non-native or invasive species, land use, over-exploitation, climate change, ultraviolet radiation, contaminants, and emerging infectious diseases (Hussain and Pandit 2012). Disease, such as the chytrid fungus, affecting boreal toads in the western United States may have its spread promoted by warm temperatures (Muths et al. 2008). In a study spanning elevations and latitudes in the Rocky Mountains, maximum daily temperature was found to explain the presence of the chytrid fungus in boreal toad populations (Muths et al. 2008). Low annual precipitation leading to shallow water levels in ponds and overexposure of toad eggs to ultraviolet-B light may be an additional factor contributing to reductions in amphibian populations (Kiesecker et al. 2001). The introduction of non-native fish into fishless mountain lakes has inadvertently introduced new predators of native western United States frogs and salamanders (Ryan et al. 2014). Several factors including disease, climate, ecology, and land use may affect amphibians, and further research is needed to clarify specific causal factors in amphibian decline.

Future climate change has a very high likelihood of further hindering amphibians and causing extirpations as a result of less snowpack, higher temperatures, and drought that reduces seasonal wetlands, a primary habitat of amphibians in the United States (Corn 2005). A northwestern United States study of the Columbia spotted frog by Hossack et al. (2013) observed that populations living in large water bodies actually got larger during severe drought, but populations in small water bodies declined during drought. Ninety-eight water bodies subject to varying land uses across Utah, Idaho, Oregon, Montana, and Wyoming were found to have negative growth rates of frogs when the waterbody size was smaller than 0.37 acres (0.15 ha) (Hossack et al. 2013). Water body depth was not reported in this study, but drought was strongly correlated with the growth of frogs. While recent inventories in National Parks in the Rocky Mountains report continued decline in amphibians, Hossack et al. (2013) observed higher colonization rates for some amphibian species in beaver-influenced wetlands in contrast to wetlands without beaver influence. In British Columbia, Gerick et al. (2014) projected that 45 to 82 percent of Great Basin spadefoot toads, northern red-legged frogs, and Pacific chorus frogs would experience summer maximum temperatures above thermal optima by 2080. Snowpack loss may also initiate earlier breeding of amphibians and raise the risk of freezing (Corn 2005); however, this is not a well-studied phenomenon.

Studies across North America that assess the vulnerability of amphibians rank them with a very high vulnerability (Coe et al. 2012; Lawler et al. 2010; Neely et al. 2011). Given that warmer and drier conditions have occurred, and are likely in the future, these conditions pose a great challenge for amphibians in the Wasatch Range and Uinta Mountains. Climate effects on amphibians are likely to be compounded by the additional impacts of stressors such as pathogens, habitat degradation, and predation. Thus, amphibians are likely to be highly vulnerable to climate change. For more information on amphibian vulnerability and methods, see the vulnerability assessments and modeling studies in table 4.

Table 4—Amphibian vulnerability assessments or other analyses providing further information.

Source	Description	Method
Coe et al. (2012)	Amphibians' (and other species) vulnerability assessment using the System for Assessing Vulnerability of Species (SAVS) in the Sky Islands of Arizona.	Expert opinion
Gerick et al. (2014)	A species distribution modeling study projecting Great Basin spadefoot toad, Northern red-legged frog, and Pacific chorus frog distribution reduction in British Columbia, Canada.	Modeling study
Lawler et al. (2009)	Northern hemisphere vulnerability of amphibians.	Modeling study
Neely et al. (2011)	Vulnerability assessment of amphibians (and other species) in the Gunnison Basin of Colorado.	Literature synthesis and expert elicitation

Macroinvertebrates

Macroinvertebrates are an important part of the aquatic food chain providing food for fish, amphibians, and birds. These organisms are large enough to see with the human eye and have no backbone. They live part or most of their life in submerged rocks, sediment, logs, and vegetation. Benthic macroinvertebrates live in the bottom of streams and lakes and can include: mayflies, stoneflies, caddisflies, beetles, midges, crane flies, dragonflies, snails, clams, aquatic worms, and crayfish. They also break down organic material by shredding, filtering, or scraping functions. Cold-adapted and cold-stenotherm macroinvertebrates (survive in a cold and narrow temperature range) predominantly perform shredding and collecting functions of organic material and are adapted to the typically steep-gradient, high-elevation mountain sites that are snowmelt-driven. Moving farther down in elevation, the mixed warm- and cold-adapted species that live in mid- and low-elevation mountain and foothills streams tend to be predominantly collectors and grazers of organic material. Warm-adapted macroinvertebrates that live in flat lowlands with wider stream channels are predominantly collectors of organic material (see fig. 4 in Poff et al. 2010).

Macroinvertebrate adaptive capacity to climate change may be enhanced where diversity and productivity are elevated. Diverse macroinvertebrate communities are found in lower gradient streams (Ward 1998), and lower elevation streams often have aquatic habitat and food resources that support the highest productivity and aquatic biodiversity (Vannote et al. 1980; Ward 1998). Also, macroinvertebrates have a relatively fast recovery period after mortality events, such as fire (5–10 year recovery) (Minshall 2003), which also raises their ability to adapt and persist.

Macroinvertebrates are sensitive to water quality, streamflow reduction, and temperature (Carlisle et al. 2014; Hamilton et al. 2010). Losses of benthic macroinvertebrates have been strongly correlated to low winter streamflows in the Wasatch Range and Uinta Mountains (Carlisle et al. 2014), increases in July temperatures, and reductions in snowfall in the Upper Colorado River and Great Basins (Poff et al. 2010). Warm-adapted macroinvertebrates may benefit from warmer temperatures and expand their range (Domisch et al. 2013), but drier conditions that reduce streamflow could hamper these populations (Poff et al. 2010). Shah et al.'s (2014) bioclimatic envelope model projected the richness of macroinvertebrate stream insect orders: Ephemeroptera, Plecoptera, and Trichoptera in North America. Their projections had the highest richness found between 40 to 48° latitude by 2080. Also, the western U.S. mountain areas were projected to increase in genus richness as a result of future climate change. Warmer temperatures could contribute to a loss of cold-adapted higher-elevation leaf litter shredders and to a gain of warm-adapted lower-elevation species with different litter processing abilities (Poff et al. 2010).

Macroinvertebrates are likely to persist with community compositions shifting to species most tolerant of environmental conditions. While warm-adapted and mixed trait species may expand, that expansion may be hampered by site conditions and land uses.

Given the moisture sensitivity and different temperature sensitivities of macroinvertebrates, their vulnerability to climate change likely spans from very high for high-elevation, cold-adapted species, to moderate or low vulnerability for warm-adapted species at lower elevations. Some warm-adapted species in these communities may not be adapted to watershed conditions in higher-elevation streams that they move into, which would raise their vulnerability to high. For more information on macroinvertebrate vulnerability and methods, see the vulnerability assessments and modeling studies in table 5.

Table 5— Macroinvertebrate vulnerability assessments or other analyses providing further information.

Source	Description	Method
Poff et al. (2010)	Benthic macroinvertebrate study of species' traits and environmental variation and climate change.	Modeling study
Shah et al. (2014)	Bioclimatic envelope model projections for macroinvertebrate species undergoing climate change across North America.	Modeling study

Beaver

Beavers offer valuable services to watersheds by their dam-building activity that can buffer the effects of reduced snowpack and earlier runoff. They typically inhabit low-gradient stream reaches (Baker and Hill 2003). Although beaver dams can restrict fish movement, as seen in Minnesota (Schlosser 1995), and may cause fish-spawning gravel to be covered with silt (Rosell et al. 2005), beaver dams promote riparian plant growth and wetland and floodplain expansion by retaining sediment and water in valley bottoms (Baker and Hill 2003; Polvi and Wohl 2012; Westbrook et al. 2011). They benefit fish and wetland species by increasing habitat complexity and buffering streamflow variations, such as those variations that may occur with climate change (Gibson and Olden 2014; Rosell et al. 2005).

Beaver populations, though variable over the 20th century, have recently increased in many areas of the western United States (Gibson and Olden 2014). While drought has been observed to reduce beaver numbers, they have continued to occupy watersheds despite severe droughts in the Greater Yellowstone Area (Persico and Meyer 2013). This study also found low and variable streamflow and ephemeral summer flows in small basins reduced beaver numbers, but the beavers may have moved to larger nearby stream channels. Beaver are also resilient to floods that can temporarily displace beavers and destroy dams, as they can rapidly rebuild their dams (Andersen and Shafroth 2010). However, beaver activity can be minimized by fire-related debris flows (Persico and Meyer 2013).

Vulnerability assessments for beaver in the Wasatch Range and Uinta Mountains are not currently available. In eastern Canada, beavers were projected to persist under climate change where plant and water sources are available. Jarema et al. (2009) concluded that beaver responses and climate change would occur at a similar pace. They assume an increase in the abundance and/or productivity of beaver primary food sources. They also assume that other forms of environmental and anthropogenic changes, for example, fire frequency, conversion of forests into agricultural and developed lands, and trapping intensity, do not override the effects of climate change in this region. Friggens et al. (2013) assessed beaver vulnerability in the Middle Rio Grande of New Mexico, giving them a score of 5 on a scale of -20 to +20 (+20 being the most vulnerable). The score resulted from beaver dependence on the continuous presence of water, although drying is projected for New Mexico. Given that beaver can be hampered by drought, flooding, and fire-related debris flows—but have historically persisted despite severe drought—they are likely to persist in the future. Thus, beaver are probably moderately vulnerable to climate change. For more information on beaver vulnerability and methods, see the vulnerability assessment studies in table 6.

Table 6—Beaver vulnerability assessments or other analyses providing further information.

Source	Description	Method
Friggens et al. (2013)	Uses the system for assessing vulnerability of species.	Literature synthesis and expert elicitation
Jarema et al. (2009)	Beaver vulnerability assessment for eastern Canada.	Climatic Envelope Model

Riparian Vegetation

Riparian vegetation depends on the flow of ground and surface water, with disturbance, site conditions, and climate structuring its composition. Riparian plant composition varies along the elevation gradients of the Uinta Mountains and Wasatch Range. Along streams above 5,500 feet elevation willows, cottonwoods, water birch, black hawthorn, alder, boxelder, and rose commonly dominate (UDOWR 2014a). At higher elevations, sedges, grasses, herbaceous species, willows, quaking aspen, and Engelmann spruce can grow around headwater streams, lakes, ponds, and wetlands. Riparian areas are commonly dominated by extensive willow communities and other plants. These riparian plants can recover relatively quickly after fire disturbance (Dwire and Kauffmann 2003).

Future warming and drying could inhibit the growth and survival of riparian and wetland plants, with the amount of inhibition varying across elevations. Neely et al. (2011) assessed riparian plants in the Gunnison Basin of Colorado and rated low-elevation riparian areas as highly vulnerable, mid-elevation riparian areas as moderately vulnerable, and high-elevation riparian areas as low to moderately vulnerable to climate change. This assessment noted that earlier snowmelt, floods, drought, lower base flows, the effects of land use, cattle grazing, and ungulate browsing, and the potential for invasive species to spread all contribute to make low- and mid-elevation riparian areas more vulnerable.

Riparian vegetation is likely to vary in its response to climate change, reflecting local hydrologic changes, non-climate stressors such as land uses, and the adaptive capacity and tolerances of resident species. A diminished water supply during the growing season is projected to have the greatest stress on riparian plants (Rood et al. 2008), with willows and low-elevation cottonwoods being the most intolerant of drought (Perry et al. 2012; Tyree et al. 1994). Lower water tables would especially stress seedlings and older cottonwoods situated farther away from streams (Rood et al. 2008). Wetlands that depend on groundwater would likely have a low vulnerability to climate change, while precipitation-driven wetlands with higher variation of water levels would likely have a high vulnerability (Winter 2000). Considering these factors, riparian vegetation is likely to have a low vulnerability at higher elevations or where groundwater supports riparian vegetation, and a high vulnerability to climate change at lower elevations where land uses hamper plants, or where surface water and ephemeral wetness, or wetness associated with a weather event or snow melt, support plants. For more information on riparian vegetation vulnerability and methods, see the vulnerability assessment studies in table 7.

Table 7—Riparian vegetation vulnerability assessments or other analyses providing further information.

Source	Description	Method
Perry et al. (2010)	Riparian ecosystem vulnerability assessment for arid and semi-arid regions of North America.	Literature synthesis
Neely et al. (2012)	Vulnerability assessment of riparian vegetation species and other species) in the Gunnison Basin of Colorado.	Literature synthesis and expert elicitation

Upland Vegetation

Vegetation plays a major role in the hydrologic function of watersheds, transpiring a portion of the precipitation that falls, providing litter and woody material for streams that increases habitat complexity, modulating snow accumulation and snowmelt, and buffering the effects of erosion as water moves through the watershed. Vegetation in watersheds of the Wasatch Range and Uinta Mountains varies along the span of elevations and different life zones (fig. 19). The structure and composition is a result of interactions between disturbance, site conditions, plant interactions, and climate.

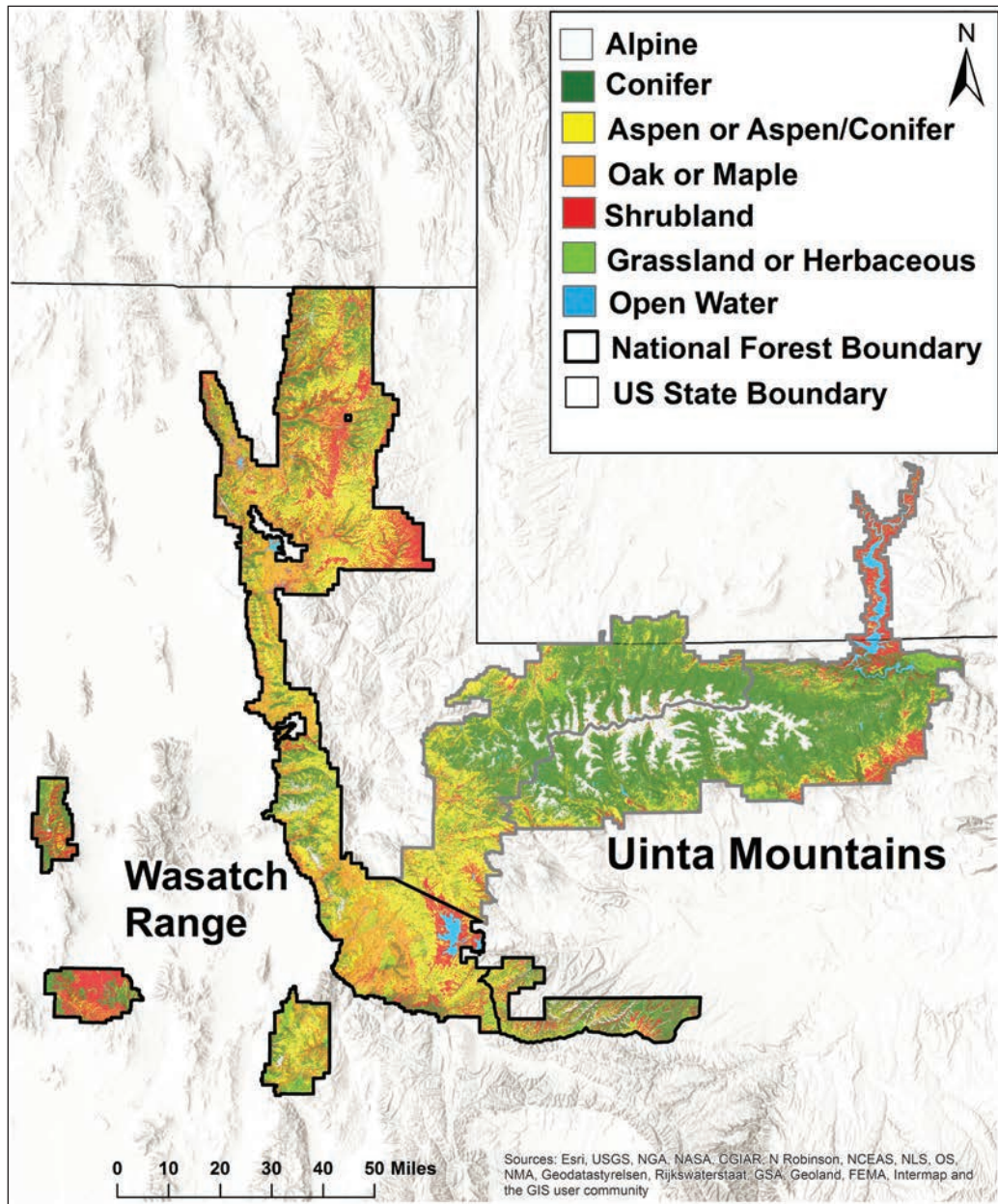


Figure 19—Vegetation on National Forest lands in the Wasatch Range and Uinta Mountains (WFS 2015). (Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community.)

Warmer and drier conditions at lowest elevations of the Wasatch Range and Uinta Mountains support vegetation types and their species adapted to these conditions. Vegetation types include grasslands and scrublands of rabbit brush, oak brush, maple brush, mountain mahogany, sagebrush, and desert shrubs. Gambel oak is uncommon in the Uinta Mountain range, but is abundant in the Wasatch Mountains (Shaw and Long 2007). Conifer and deciduous trees dominate above the foothills to treeline at about 11,500 feet elevation. Ponderosa pine is more common in the low elevations and south slope of the Uintas and in piñon-juniper woodlands in the foothills of the Uinta Mountains and Wasatch Range. Montane areas have aspen (especially abundant in the western Uinta Mountains and Wasatch Range), white fir (uncommon in the Uintas), Douglas-fir, and some occurrences of lodgepole pine. In the subalpine areas, lodgepole pine, Engelmann spruce, and mixed Engelmann spruce-subalpine fir dominate; there are few occurrences of limber pine. Lodgepole pine is more prevalent in the Uinta Mountains (Shaw and Long 2007). Above treeline, alpine meadows and grasslands form a mosaic landscape with alpine fell fields, rock outcrops, wetlands and high-elevation lakes (fig. 20) (Ostler and Harper 1978; Shaw and Long 2007).

Plants may adapt to the expected changes in climate through genetic evolution (small genetic changes from one generation to the next that are an adaptive response to environmental conditions) or by plasticity (the ability of an organism to develop observable changes in characteristics and behavior to adapt to environmental conditions).



Figure 20—High elevation lake, Uinta Mountains (photo: Mark Muir, Ashley National Forest).

Franks et al.'s (2014) review of 38 studies across the globe found that all studies reported plant plastic or evolutionary responses to climate change, and 26 studies documented both responses. Climate changes may be too fast for these adaptive plant responses to keep pace, a conclusion of 8 in 12 studies investigating this aspect (Franks et al. 2014). They state, however, that further study is needed to understand plastic and evolutionary responses to make species and trait-specific predictions about how plants may respond to climate change.

For the Gunnison Basin, Neely et al. (2011) reported that Colorado juniper woodlands, sagebrush shrub lands, and montane grasslands had low vulnerability, since these plant communities are tolerant of hot and dry conditions and will likely expand their range upslope or keep stable populations. Ponderosa pine, oak, mountain shrublands, and montane sagebrush were also assessed as having low vulnerability, given their potential to persist and increase their range upslope. Lodgepole pine, aspen, and spruce-fir were assessed as having moderate vulnerability, with a risk of being reduced to less than 50 percent of their current cover. Warmer temperatures, drier conditions or more frequent drought, continued insect outbreaks, and more frequent and intense fires were factors contributing to this rating. Alpine vegetation was rated with high vulnerability since trees may encroach and displace alpine plants with little or no alternate habitat to move to as climate becomes warmer (also see "Range Shift Capacity" section). Forest expansion into new areas is slow, as forested areas in watersheds adjacent to streams can take decades to become mature forests after disturbance events; for example, subalpine spruce-fir (Baker and Veblen 1990).

Vegetation in the watersheds of the Uinta-Wasatch-Cache and Ashley NFs is likely to respond in a complex manner across the landscape with climate change and environmental conditions driving species' responses to persist, expand, or contract. Vegetation in areas at their limit of physical heat and drought tolerance, or in areas where migration opportunities are limited, are likely to have a high vulnerability to climate change. Vegetation in areas at the limit of physical cold tolerance, or near places where suitable migration opportunities exist, are likely to have a low vulnerability to climate change as these species are likely to persist and expand. An overall reduction in forested areas is projected as temperatures warm in the Southwestern States of Utah, Colorado, Arizona, and New Mexico (Notaro et al. 2012). Climates suitable for grasslands, desert scrub, and montane scrub communities may replace climates that are currently suitable for upslope forest types (Hansen and Phillips 2015). Biodiversity may be lower in the future, as Notaro et al. (2012) simulated a loss of diversity in high-elevation forests with climate warming. Studies point to low vulnerability of vegetation at low elevations with increasing vulnerability moving to higher elevations. For more information on vegetation vulnerability and methods, see the vulnerability assessment studies in table 8.

Table 8—Vegetation vulnerability assessments and modeling studies providing further information. *Indicates this study is included in the discussion of this assessment.

Source	Description	Method
Hansen and Phillips (2015)*	Synthesis of bioclimatic envelope modeling studies projecting vegetation types and species changes using climate scenarios.	Synthesis of modeling studies
Neely et al. (2012)*	Vulnerability assessment of vegetation species (and other species) in the Gunnison Basin of Colorado.	Literature synthesis and expert elicitation
Notaro et al. (2012)*	Bioclimatic envelope and dynamic global vegetation modeling study projecting vegetation changes with climate scenarios for the southwestern United States.	Modeling
Halofsky et al. (2017)	Vegetation type vulnerability assessment for the Northern Rockies. Full assessment forthcoming.	Literature synthesis, modeling study, expert elicitation

Sensitivity to Extreme Climatic Events (Drought, Heat, Floods)

Summary	
Wasatch Range vulnerability: Very high	Uinta Mountain vulnerability: Moderate to very high
Sensitivity to drought: Wasatch Range watersheds are likely to have a very high sensitivity since watershed function is affected by drought, especially in areas with gravely, shallow soils, or on southerly aspects that receive higher insolation. Droughts may increase in the future, affecting watershed processes and hindering biota, lowering water quality, and altering sediment supply and channel shape.	Sensitivity to drought: Uinta Mountain watersheds are likely to have very high sensitivity as watershed function is affected by drought (see summary to left). While the higher elevations of the Uintas are cooler and receive more moisture than lower elevation, these watersheds are still subject to drought.
Sensitivity to extreme heat: Wasatch Range watersheds are likely to have a high sensitivity to extreme heat events that are likely to increase with climate change, especially at lower elevations. A factor that can lower the sensitivity to warming is the influence of groundwater that has been cooled underground and can mitigate stream temperatures downstream of springs.	Sensitivity to extreme heat: Uinta Mountain watersheds are likely to have a moderate sensitivity to extreme heat. A large amount of area in the Uintas is at cooler elevations above the montane life zone, which is projected to experience less extreme heat than lower elevations. As in the Wasatch Range, a factor that may lower the sensitivity to warming is the influence of groundwater that has been cooled underground, which can mitigate stream temperatures downstream of springs.

<p>Sensitivity to floods: Wasatch Range watersheds are likely to have a very high sensitivity to flooding, which may increase in the future. Flooding can destroy infrastructure, restructure channels, and cause debris flows. Watershed characteristics that contribute to the sensitivity to flooding events are low-elevation areas with rain or mixed rain-snow hydrology, low-gradient streams, or streams that have large amounts of upslope area, recently burned watersheds, or drainages with steep terrain or canyons that are sensitive to flash floods. Flooding can, however, offer long-term benefits, creating more stream habitat complexity and adding wood and sediment to streams.</p>	<p>Sensitivity to floods: Uinta Mountain watersheds are likely to have moderate sensitivity or degree to which watershed function is affected by floods (see summary to left). The higher elevation areas with less upslope contributing area, flatter terrain, calcareous and less erosive geology, and a lower fire risk reduce the flooding sensitivity to moderate.</p>
<p>Summary of literature information depth supporting vulnerability:</p> <ul style="list-style-type: none"> • Drought projections are based on both temperature and precipitation with the former having higher certainty of model agreement. Drought sensitivity is supported by nine studies. • Temperature projections have high model agreement, and five studies are included to support extreme heat sensitivity. • Flooding and precipitation projections have higher uncertainty than temperature, and flooding sensitivity of watersheds are supported by 16 studies. 	

Sensitivity to Drought

Droughts, or a deficiency in precipitation over an extended period, in the Wasatch Range and Uinta Mountains are mostly associated with unusually low cold-season (October–March) precipitation, a season during which most of the annual precipitation falls (MacDonald and Tingstad 2007). This decreased precipitation lengthens the duration of summer water deficits. Drought is projected to be more intense and potentially last longer (see “Dependence on Specific Hydrologic Regime” section below for further information). Streams were found to be most sensitive to abrupt changes in climate such as drought that alter erosion processes and sediment movement, which was observed in the San Juan Mountains of Colorado (Johnson et al. 2011). Drought or reduced flows on the Duchesne River in Utah were observed to cause gravel-bed reaches to narrow (Gaeuman et al. 2005). Sand-bed reaches were found to replace sinuous reaches with straighter ones that were subsequently down cut and narrowed when streamflow and flooding magnitude increased (Gaeuman et al. 2005). Lower streamflow reduces sediment accumulation, which can lead to more erosion of the stream bank and bed, as observed in low-gradient streams of the Big Horn Mountains in Wyoming (Wohl et al. 2007). Higher elevations may not experience as much drying and drought since cooler temperatures and more precipitation are characteristic of these areas (Lukas et al. 2014). However, some snowpack loss is projected for higher elevations (Klos et al. 2014), which would contribute to drier conditions late in the growing season that could intensify the effects of drought and hamper biota. Aquatic species are highly sensitive to drought, as discussed in the “Vulnerability of Cold-Adapted, Foundation, or Keystone Species to Climate Change” section above; drought reduces and disconnects habitat, reduces food sources, and can deteriorate water quality.

Gravelly, sandy soils have less water retention capacity than finer grained soils that have a higher ability to retain moisture during drought. In the Wasatch Range and Uinta Mountains, soils are typically Entisols, Inceptisols, or Alfisols. Entisols and typically have no horizon and are basically unaltered from parent material. Inceptisols are weakly developed, and Alfisols contain clay that underlies the timbered lands. Mollisols are rich in organic matter and dominantly underlay meadows, aspen forests, sagebrush and grass, and mountain brush sites (McNab et al. 2010), although Histosols, Vertisols, Alfisols, Entisols, and Inceptisols can be associated with these vegetation communities in some cases. Deeper soils, high in organic matter and silty content, retain more water than sandier or rockier soils on south-facing slopes that receive more insolation as found in southern Idaho (Geroy et al. 2011) and northern Utah (Burke and Kasahara 2011).

Given the potential for drought to alter erosion processes and hinder biota, watersheds of the Wasatch Range and Uinta Mountains have a very high sensitivity to drought. The magnitude of drought effects are likely to vary across elevations in different soil and topographic conditions in these mountain ranges.

Sensitivity to Extreme Heat

More extreme heat is projected to occur. Climate model projections compared to the late 20th century indicate an annual increase of 5 to 10 days that temperatures exceed 95 °F by the mid-21st century in northern Utah (Kunkel et al. 2013). The most extreme heat days are projected for the lower elevations around the Uinta Mountains and Wasatch Range (see fig. 23 in Kunkel et al. 2013). Extreme heat may disproportionately affect species living at the limit of their heat tolerance; for example, vegetation, benthic communities, salmonids, and Colorado River cutthroat trout (see “Vulnerability of Cold-Adapted, Foundation, or Keystone Species to Climate Change” section).

Springs, seeps, and other groundwater sources are common in many areas of the Uinta-Wasatch-Cache and Ashley NFs (fig. 21). They may reduce streams’ sensitivity to warmer conditions from climate change. Stream temperature warming rates have been documented in the northwestern United States as slower than air temperature warming rates. In some cases, stream warming was less than 50 percent of the rate of air temperature increases (Isaak et al. 2012; Luce et al. 2014). Where the groundwater/spring influx was a high contribution to streams, the rate of stream warming relative to air temperature warming was even lower. Deep groundwater contributions to stream-flow were found to lower stream temperatures in the western Cascades of Oregon (Tague et al. 2008). Some areas of the Uinta Mountains have groundwater that travels through carbonate rocks in karst features where it is discharged from large springs at lower elevations. The travel time of water can be 1 to 14 days depending on the distance traveled (Spangler 2005). In these cases, the mitigating effects of groundwater cooling to streams may not be as strong as when water remains underground for longer periods.

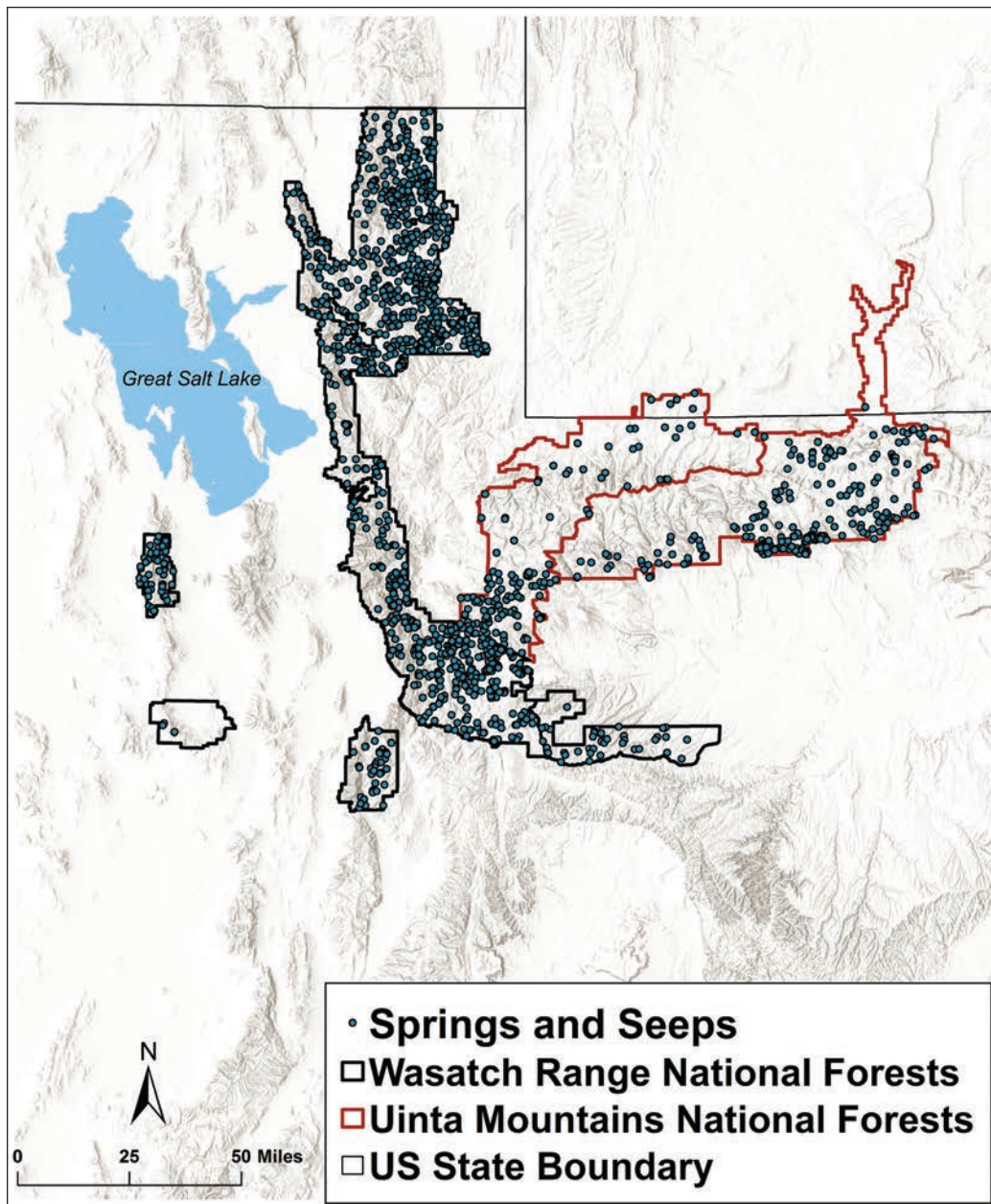


Figure 21—Locations of over 5,700 springs on the Uinta-Wasatch-Cache and Ashley National Forests. (Data source: NHDPlus2 (EPA 2012). Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap, and the GIS user community.)

The presence of springs and seeps may reduce the effects or area affected by extreme heat at various locations across the Wasatch Range and Uinta Mountains. Extreme heat, however, is projected to be more pronounced at lower elevations as opposed to higher elevations. The Wasatch Range is given a high vulnerability since projections show more extreme heat potential at the lower elevation areas that comprise a larger share of the Wasatch Range area. The Uinta Mountains are given a moderate vulnerability since the majority of area is in higher elevations are not projected to be as affected by extreme heat.

Sensitivity to Floods

Flooding in the Uinta Mountains and Wasatch Range is associated with either unusually high accumulations of snowpack or extreme rainfall events (Bekker et al. 2014; Carson and Munroe 2005; Steenburgh et al. 2000). The incidence of flooding in the region is expected to increase (see “Dependence on Specific Hydrologic Regime” section below). Flooding affects various areas of watersheds differently according to the amount and form of precipitation and geomorphic structure of drainages. Low-gradient streams have less constrained stream banks, slower flows, and finer grained sediment (see streams in green, fig. 22). The low-gradient configuration is more sensitive to

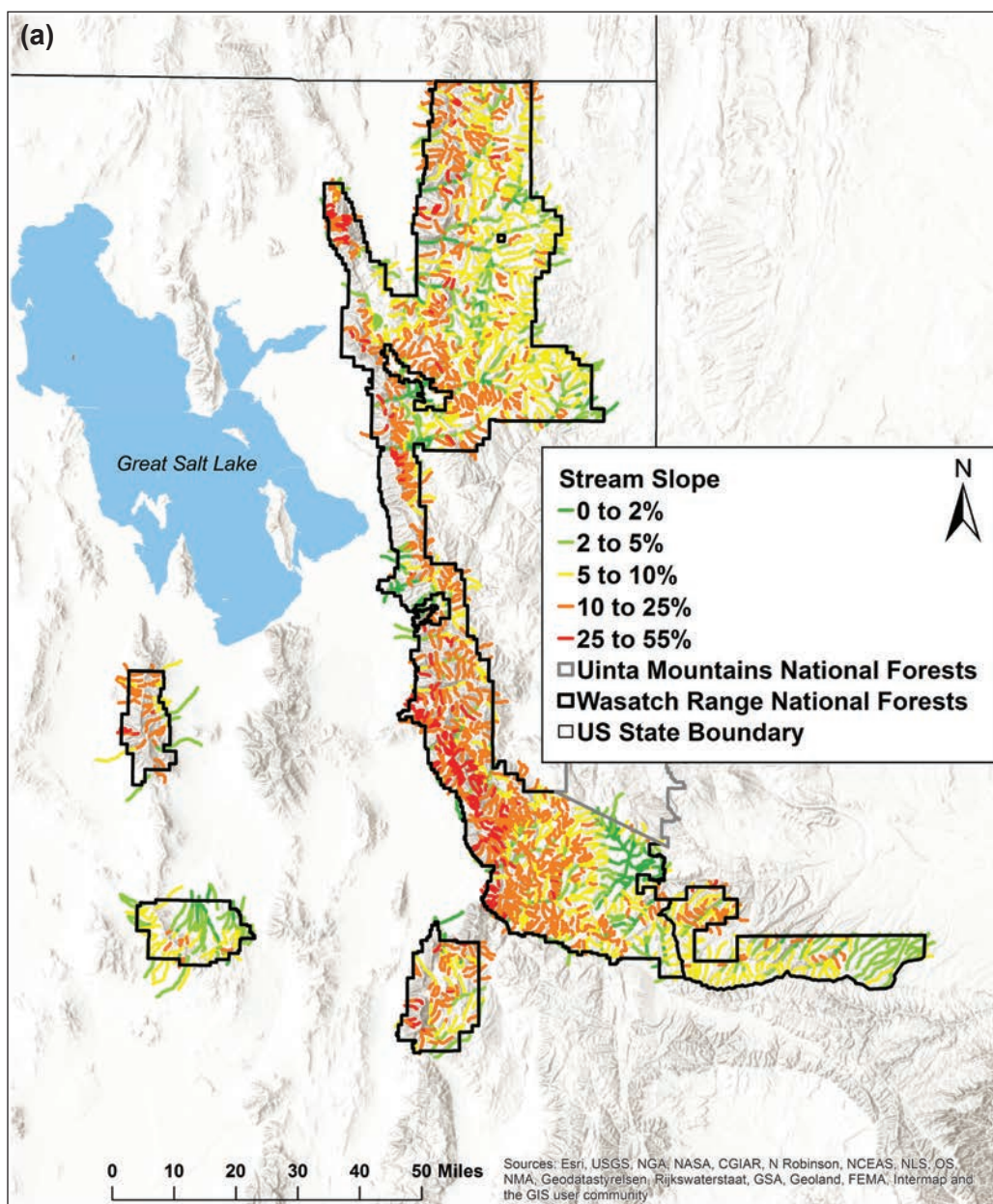
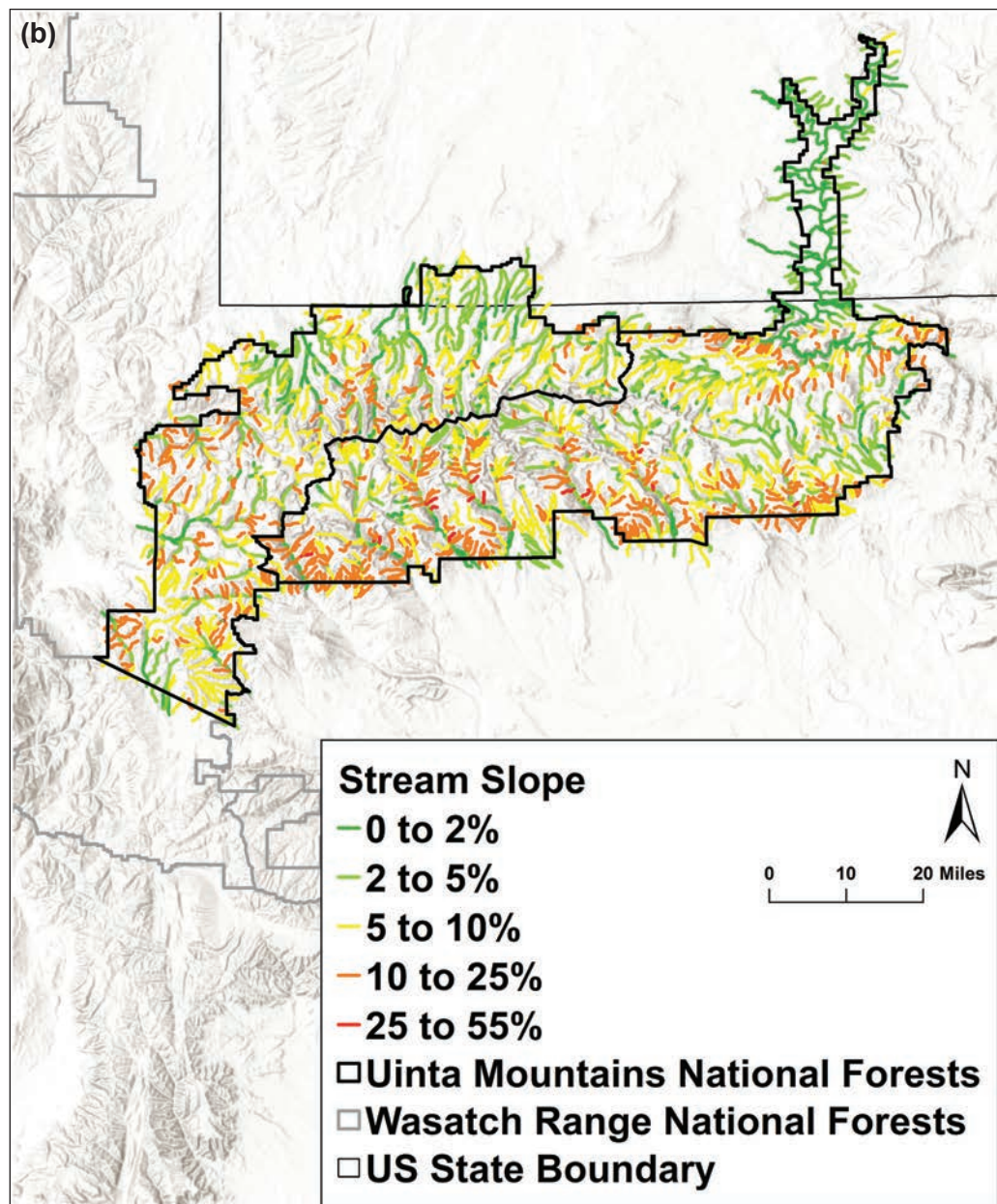


Figure 22—Stream slope percent for National Forest land streams of the Wasatch Range (a) and Uinta Mountains (b). (Data source: NHDPlus2 (EPA 2012). Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap, and the GIS user community.)

flooding as there is more risk of pools filling with sediment during flooding (Wohl et al. 2007). High-gradient streams tend to have more constrained flows with coarser stream beds and rapid response times (Wohl et al. 1993) (see streams >10 percent slope in red and orange in fig. 22). These steeper streams are more resistant to erosion and less sensitive to flooding (Wohl et al. 2007), but there is a greater hazard of flash flooding in constrained canyons, and gullied stream channels that concentrate streamflow.

The sensitivity of watersheds to flooding depends also on elevation and watershed size. Flooding in the Uinta Mountains was found to be driven by high winter precipitation with cooler late-winter and spring temperatures that preserved high snowpacks



that eventually melted (Carson 2007). In addition to snowmelt driven flooding, flood discharges in large basins ($>2,500 \text{ mi}^2$) was found to be highest during low intensity, long duration precipitation events in the lower Colorado River Basin (Orem and Pelletier 2012). Lower elevations have the largest amount of upslope area contributing to streamflow, which thereby increases flooding potential. Orem and Pelletier (2012) found that short duration, intense precipitation events resulted in the highest amount of flood discharge in small basins ($<2,500 \text{ mi}^2$) in the lower Colorado River Basin. Watersheds with winter temperatures around 0°F have transient snow-rain precipitation and can produce flooding during rain-on-snow events (Hamlet and Lettenmaier 2007). These areas that receive snow during a cool period, then followed by a warmer period and rain, can have intense flooding (Kunkel et al. 2013). The number of rain-on-snow events across the western United States has high variability but was observed to have increasing trends at elevations between 6,500 and 9,800 feet elevation from 1949 to 2003 (McCabe et al. 2007). High-elevation, snow-dominated watersheds have less upslope area contributing to runoff, and these areas accumulate snow in winter that delays their contribution to runoff (Hamlet and Lettenmaier 2007), which suggests less intensity of floods and lower flooding sensitivity in these higher-elevation areas.

Geology can play a role in the magnitude of erosion from flooding. Geology influences flow rates and runoff pathways and regulates streamflow regimes. The Uinta Mountains and Wasatch Range geology is dominated by quartzite, sandstones, shales, conglomerates, and limestone, with some karst features (Spangler 2005) (figs. 23 and 24). Karst features are calcareous (composed of calcium carbonate, limy, or chalky), and found on the south slope of the Uinta Mountains. Wohl et al. (2007) observed that calcareous geologies in the Big Horn Mountains of Wyoming were less responsive to erosion events.

In general, flooding can adversely affect biota, restructure channels, fill lakes and reservoirs with sediment, reduce water quality, and destroy infrastructure. Flooding can wash out beaver dams, and flood outbursts have caused harmful accidents involving humans.

Postfire watersheds in steep terrain (fig. 25) are often stripped of vegetation and become most sensitive to storm flooding. These burned watersheds can have peak flows orders of magnitude higher than before fire, as Neary et al. (2011) documented in the San Francisco Peaks of Arizona. Debris flows are common in postfire watersheds, and even small rain inputs can trigger these erosion events. A modeling study by Gartner et al. (2008) suggested that slopes greater than 30 percent were at a critical angle for significant erosion from debris flows in basins burned by moderate or high severity fire in Colorado, Utah, and California. Flooding can, however, offer long-term maintenance benefits to streams, creating new channels and increasing habitat complexity and diversity as wood and sediment are added to stream channels (as was found in the Pacific Northwest) (Benda et al. 2004, 2003; Miller et al. 2003).

In summary, low elevations and areas with mixed rain-snow precipitation regimes, such as in the Wasatch Range, have a higher potential for flooding. Model projections for precipitation and flooding events have some disagreement across the different

climate models; however, there is high model agreement that winters in the Wasatch Range and Uinta Mountains will become wetter. Low-gradient streams are most sensitive to channel structure changes with flooding. Postfire, steep-sloped watersheds, or constrained canyons, or steep stream channels are sensitive to flash flooding. The Wasatch Range has many high-gradient streams, and when combined with the potential for future mixed rain-snow precipitation events, a very high vulnerability to flooding is likely. Higher elevations or areas with less upslope contributing area, and watersheds underlain with calcareous geology such as in the Uinta Mountains, may be less sensitive to erosion events from flooding. A moderate vulnerability score is assigned to the Uinta Mountain watersheds.

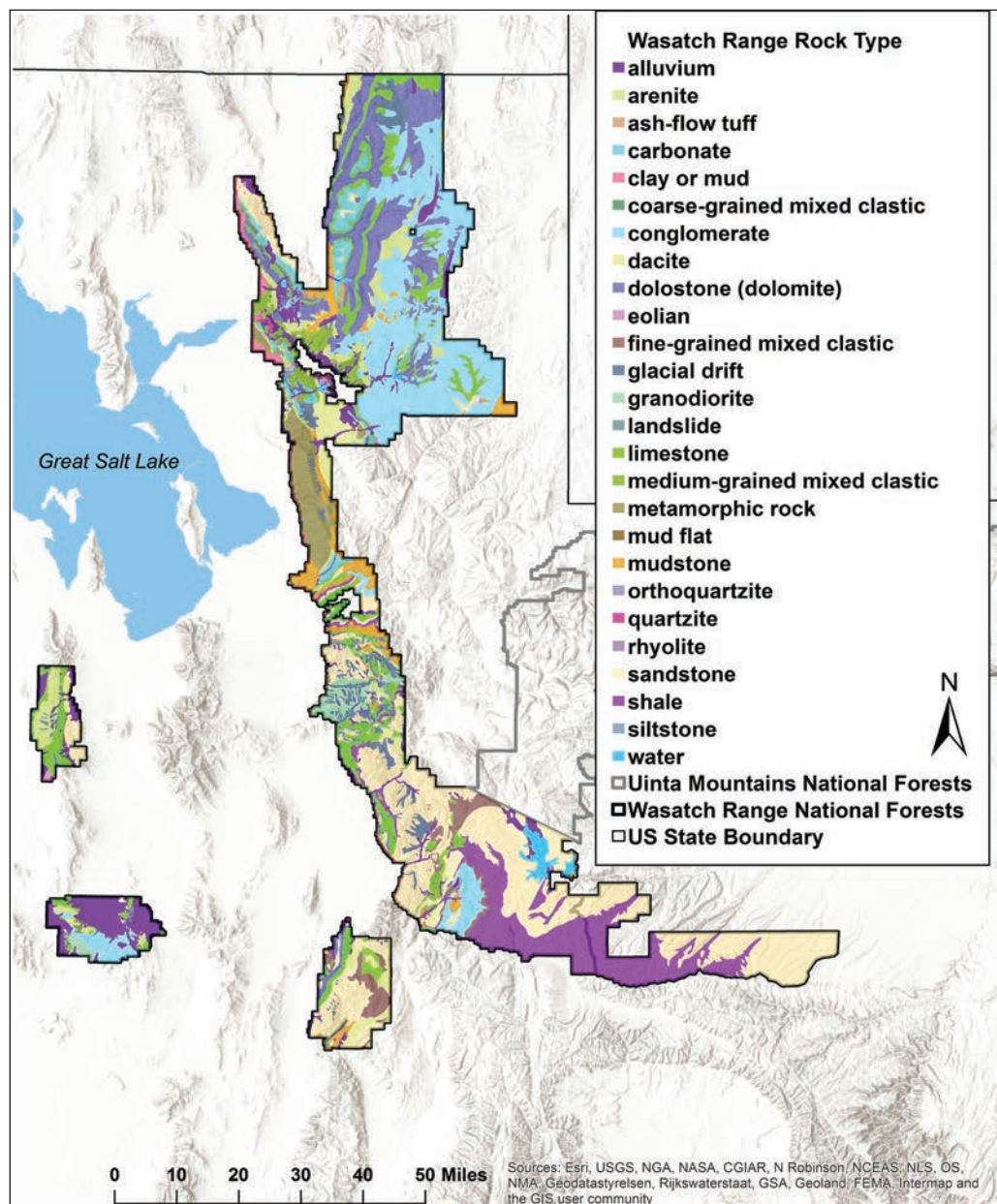


Figure 23—Wasatch Range Rock Types. (Data source: U.S. Geologic Survey, <http://mrdata.usgs.gov/geology/state/>. Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community.)

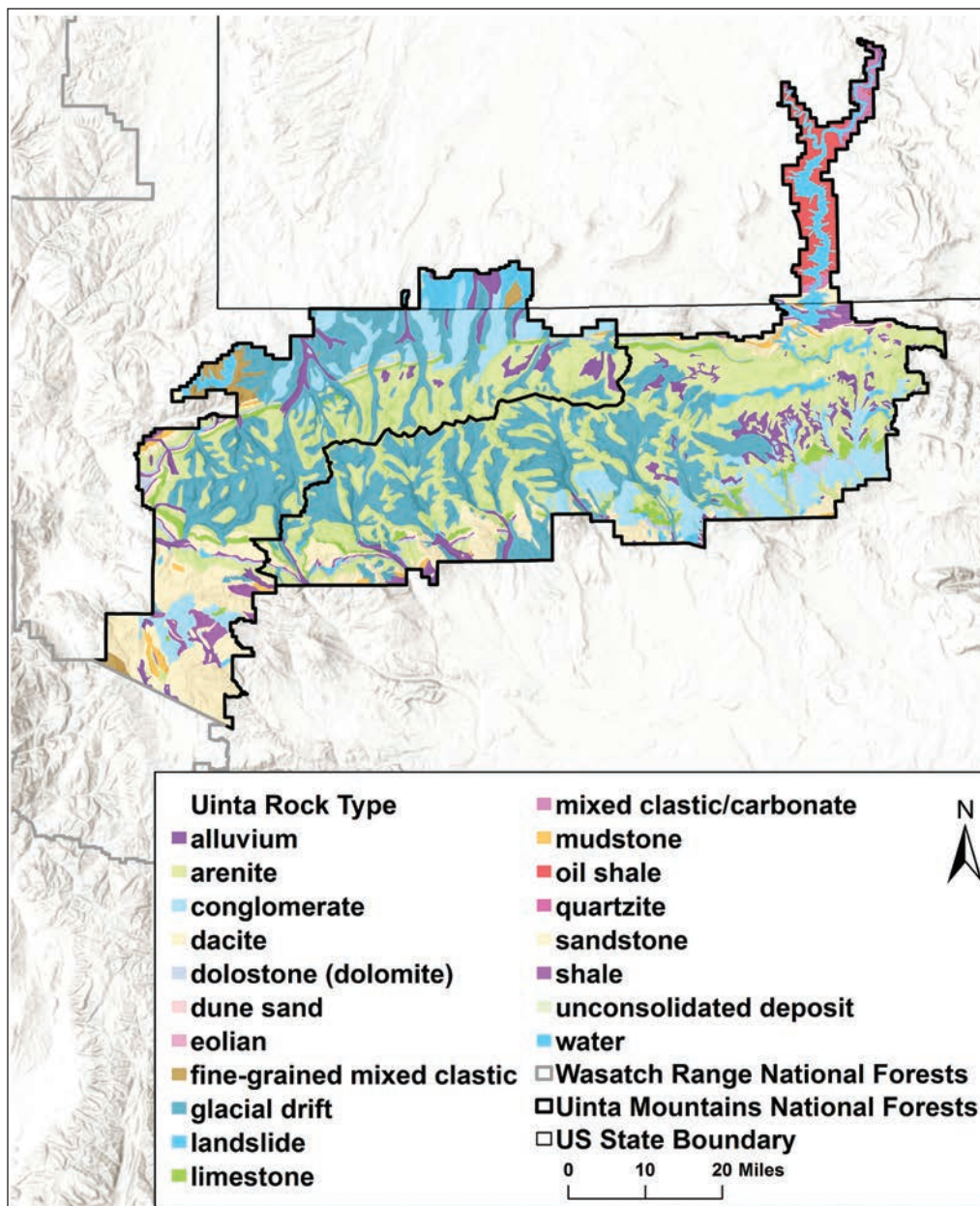


Figure 24—Uinta Mountain Rock Types. (Data source: U.S. Geologic Survey, <http://mrdata.usgs.gov/geology/state/>. Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community.)



Figure 25—Steep slope watershed (photo: Mark Muir, Ashley National Forest).

Intrinsic Adaptive Capacity

Summary	
Wasatch Range vulnerability: Moderate	Uinta Mountain vulnerability: Moderate
Factors raising adaptive capacity: <ul style="list-style-type: none"> ○ The inherent ability of watersheds to accommodate or cope with climate change impacts is good for most Wasatch Range watersheds because they have good forest cover and moderate fire effects, aquatic habitats, and riparian and wetland conditions. 	Factors raising adaptive capacity: <ul style="list-style-type: none"> ○ The inherent ability of watersheds to accommodate or cope with climate change impacts is good for most Uinta Mountain watersheds because they have good forest cover, aquatic habitats, and riparian and wetland conditions. Bark beetles have reduced forest cover by causing mortality of lodgepole pine in the northwestern slope. Fire effects are moderate for almost all of the watersheds.
Factors lowering adaptive capacity: <ul style="list-style-type: none"> ○ The ability of watersheds to accommodate or cope with climate change is poor for some Wasatch Range watersheds that have poor forest cover, aquatic habitats, and riparian and wetland conditions. 	Factors lowering adaptive capacity: <ul style="list-style-type: none"> ○ The ability of watersheds to accommodate or cope with climate change is poor in a very small minority of Uinta Mountain watersheds that have poor forest cover, aquatic habitats, and riparian and wetland conditions.
Summary of literature information depth supporting vulnerability: <ul style="list-style-type: none"> • The U.S. Forest Service Watershed Condition Assessment is used to classify conditions, and it is based on professional judgment used to define the conditions of watersheds. • A highly cited book from a riparian expert (R. Naiman 2010) and six other studies support how functioning riparian and upslope conditions improve adaptive capacity. Five studies support how fire effects can disrupt watershed function, which would lower adaptive capacity. 	

Factors That Strengthen Adaptive Capacity to Climate Change

Functioning Watershed Condition

Adaptive capacity can be high where vegetation cover reduces erosion and loss of soil (Zhou et al. 2008). Fire can hinder watershed function by removing vegetation and increasing sediment yields, flooding and debris flows, and degrading water quality (Goode et al. 2012; Luce et al. 2012; Rhoades et al. 2011; Rieman and Isaak 2010; Yue et al. 2013). Functioning riparian areas and aquatic habitats in good condition increase adaptive capacity in several ways. Riparian vegetation can add woody debris and leaf litter inputs to streams and support insects and fish (Naiman et al. 2010). Stream banks are stabilized by riparian vegetation, and stream temperatures can be lowered when shaded by plants or trees. Also, riparian plants can filter pollutants such as nitrogen and sediment-bound phosphorus with the degree of filtering dependent on the plant assemblage (Naiman et al. 2010).

The Forest Service Watershed Condition Assessment (USDA 2013) assessed the functioning condition of watersheds, and here we include terrestrial and aquatic factors for forest cover and fire effects, riparian/wetland vegetation, and aquatic habitat that were assessed for the Uinta-Wasatch-Cache and Ashley NFs. Most watersheds were classified as having good forest cover and fair fire effects (see 260 green watersheds in

fig. 26 (a), and 274 watersheds in fig. 26 (b). Forest cover condition was classified by professionally judging the potential for altered hydrologic and sediment regimes from losing forest cover on forest lands. The fire effects were also determined by using professional judgment to classify the potential of altered hydrologic and sediment regimes because of departures from historical ranges of variability in vegetation, fuel composition, fire frequency, fire severity, and fire pattern (USDA 2013).

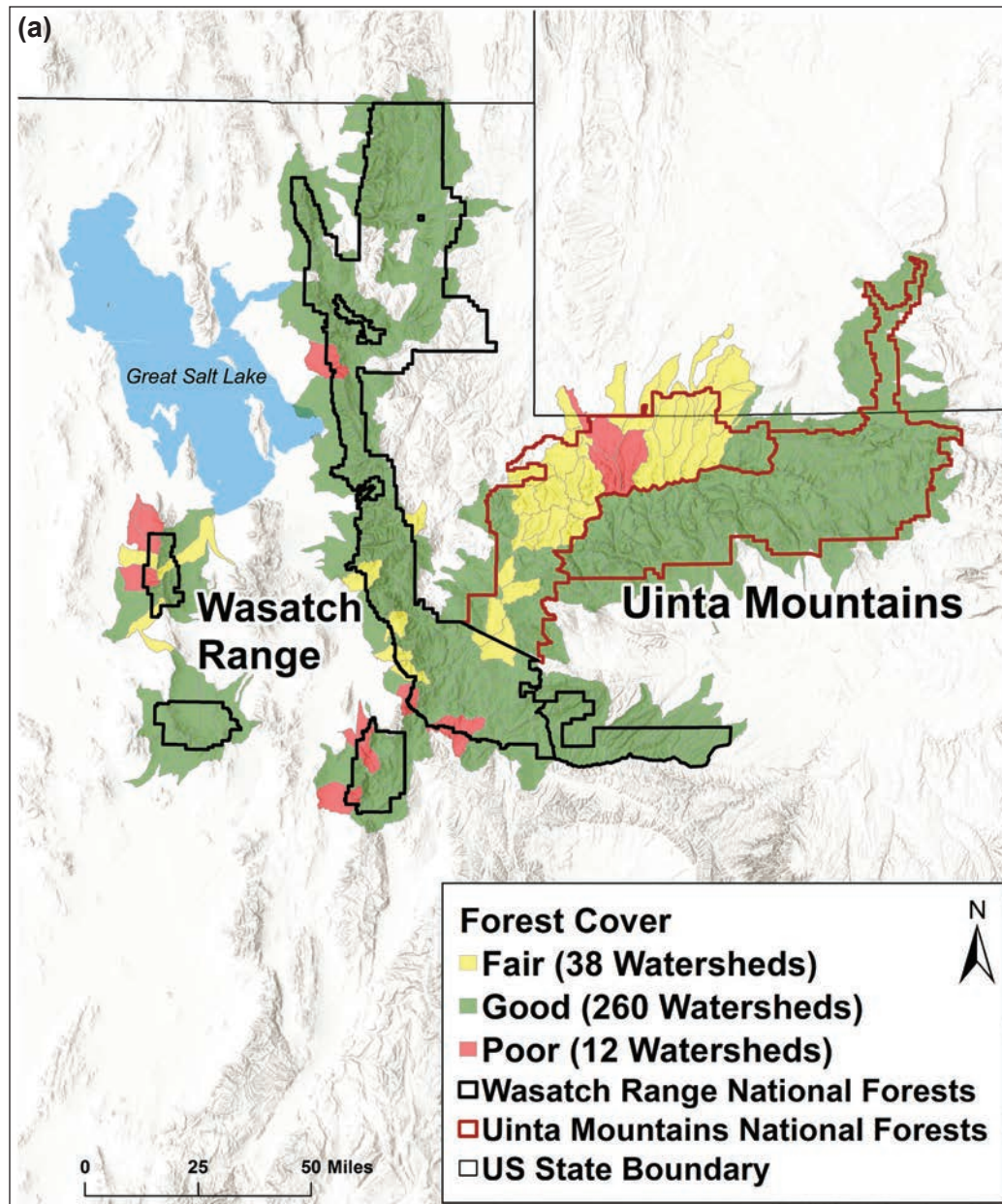
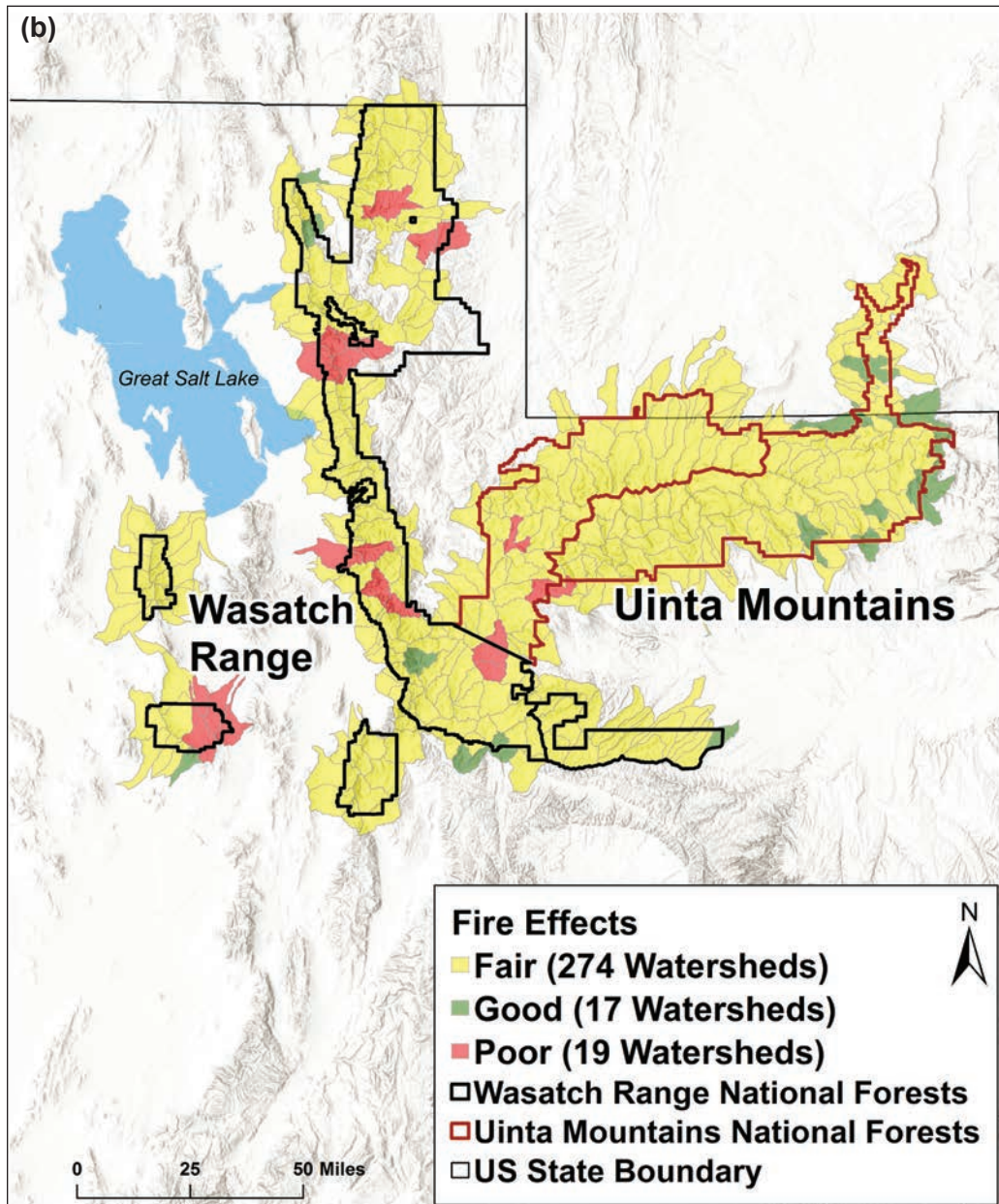


Figure 26—Forest Cover (a) classified by the amount of land that does not support forest cover: minor (Good), moderate (Fair), and high (Poor). Fire Effects (b) classified as low likelihood (Good), moderate likelihood (Fair), or high likelihood (Poor) of losing defining ecosystem components because of the presence or absence of fire. Note: Forest cover conditions reflecting bark beetle outbreaks and fire effects can change rapidly and may not be entirely reflected in these maps that were derived from a 2010 version of the watershed condition assessment. (Data source: Wasatch Range and Uinta Mountains on the Uinta-Wasatch-Cache and Ashley National Forests, U.S. Forest Service Watershed Condition Framework (USFS 2011). Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community.)



Several watersheds have riparian/wetland vegetation. Aquatic habitat is in good or fair condition on the Uinta Mountains and scattered throughout the Wasatch Range (see 143 green and 130 yellow watersheds in fig. 27, and 138 green and 153 yellow watersheds in fig. 27, total watersheds is 310). Riparian/wetland vegetation condition was determined using professional judgment to classify the function and condition of riparian vegetation along streams, water bodies, and wetlands. Aquatic habitat condition was determined using professional judgment to classify habitat fragmentation, large woody debris, and channel shape and function.

In areas where watersheds, forest cover, fire effects, aquatic habitat, and riparian and wetland conditions are reported to be in good condition, the adaptive capacity to floods, heat, and drought is assumed to be high.

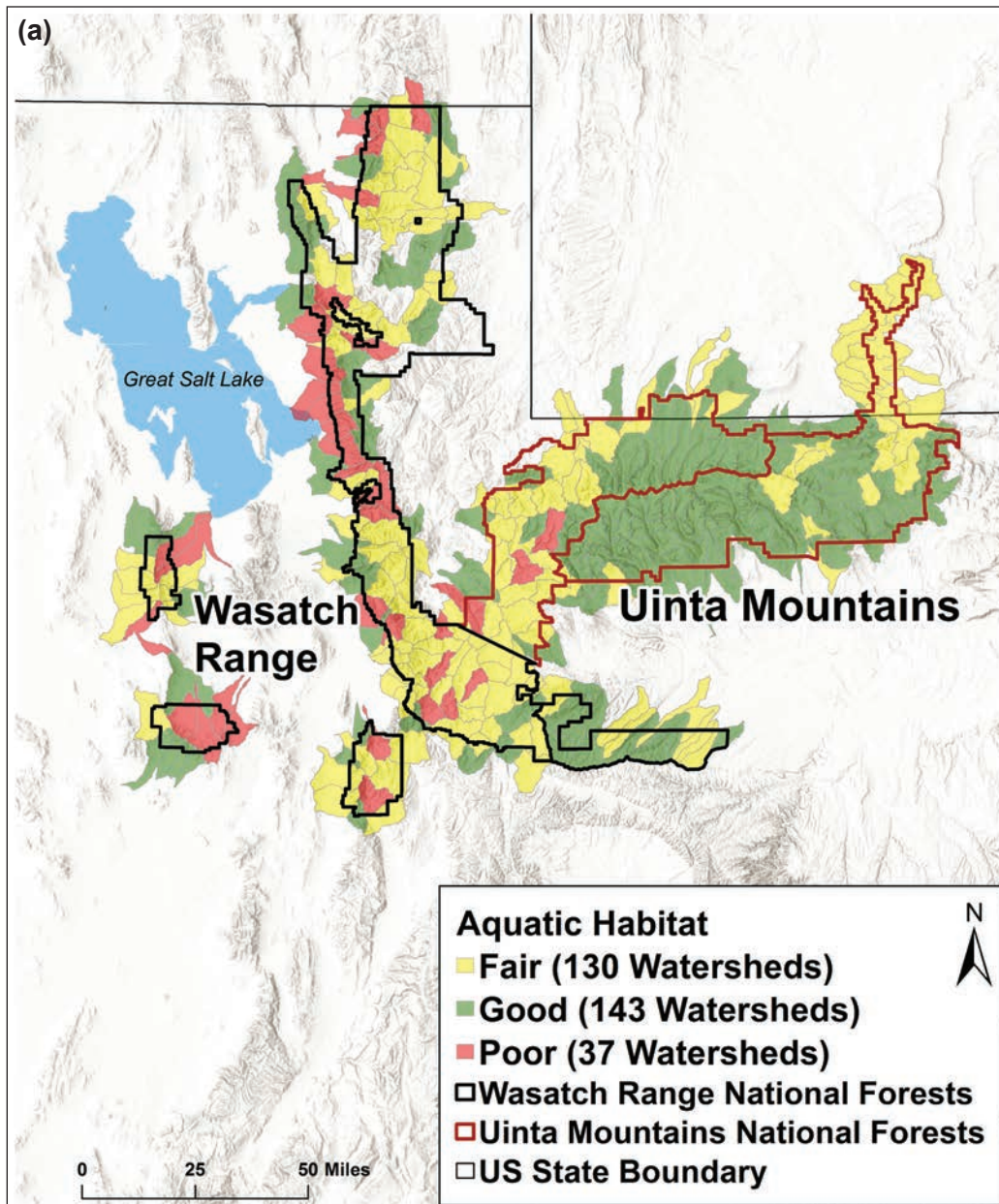
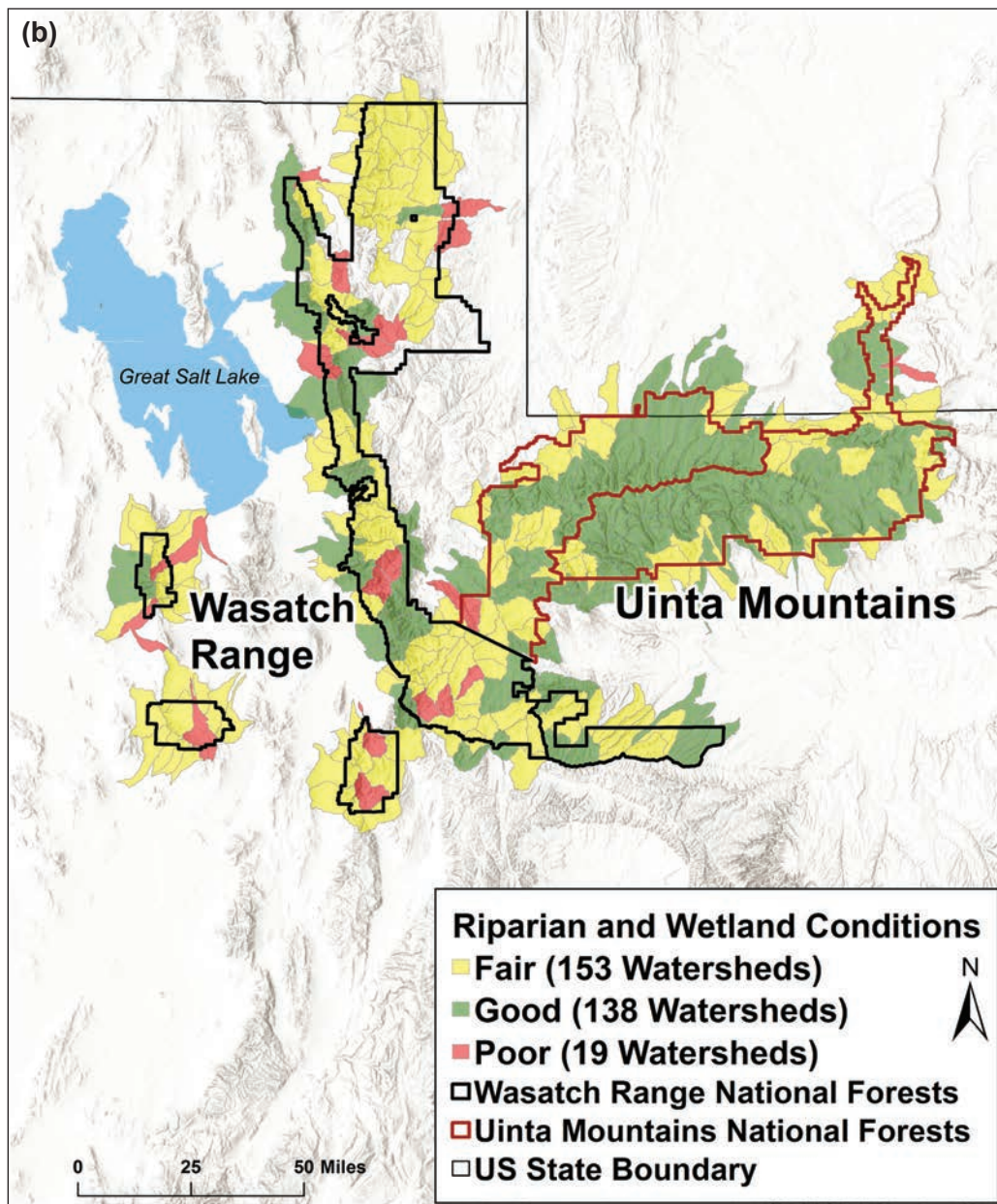


Figure 27—Aquatic Habitat Condition (a) classified by whether watershed supports large continuous blocks of high-quality aquatic habitat and high-quality stream channel conditions (Good), or the watershed supports medium to small blocks of contiguous habitat. Some high-quality aquatic habitat is available, but stream channel conditions show signs of being degraded (Fair), or the watershed supports small amounts of continuous high-quality aquatic habitat. Most stream channel conditions show evidence of being degraded by disturbance (Poor). Riparian and Wetland Condition (b) is classified by whether native vegetation is functioning properly throughout the stream corridor or along wetlands and water bodies (Good); and disturbance partially compromises the properly functioning condition of native vegetation attributes in stream corridor areas or along wetlands and water bodies (Fair); or large percent of native vegetation attributes along stream corridors, wetlands, and water bodies is not functioning properly (Poor) on the Uinta-Wasatch Cache and Ashley National Forests, USDA Forest Service Watershed Condition Framework (USFS 2011). (Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community.)



Factors That Weaken Adaptive Capacity to Climate Change

Degraded Watershed Condition

In areas where riparian or upslope vegetation have been damaged—removed mechanically or by fire—the adaptive capacity to flooding, heat, and drought is lower (see the 12 watersheds in red, fig. 26 (a)). Watersheds may have more erosion when vegetation cover is lacking, as was demonstrated in China (Zhou et al. 2008). Degraded vegetation conditions can lead to reduced woody debris and leaf litter additions to streams, which can hamper insects and fish. The capacity of riparian vegetation to filter pollution, stabilize stream banks, cool stream temperatures, and mitigate erosion from flooding is lowered when it is in poor condition. Poor aquatic habitat also lowers adaptive capacity in several watersheds of the Wasatch Range, particularly on the Wasatch Front (see the 37 red watersheds, fig. 27 (a)).

Dependence on Specific Hydrologic Regime

Summary	
Wasatch Range vulnerability: Very high	Uinta Mountain vulnerability: High
Watersheds of the Wasatch Range depend on a snow-dominated hydrologic regime, which is projected to become more rain-dominated. Temperature warming may especially affect these watersheds as more rain falls instead of snow. This will lower streamflow, shift runoff timing earlier, and reduce late-season water availability, hindering biota with reduced habitat, and increasing the likelihood of intermittent flows of perennial streams. Drought that is likely to be more common and intense in the future can reduce channel maintenance benefits, while flooding that may possibly become more frequent in the future will affect erosion processes.	Watersheds of the Uinta Mountains depend on a snow-dominated hydrologic regime, which is projected to largely remain snow-dominated. Uinta watersheds may not experience as much snowpack loss, warming, or drying as the Wasatch Range. However, temperature warming is likely to have effects on Uinta Mountain watersheds (see summary to left).
Summary of literature information depth supporting vulnerability: <ul style="list-style-type: none"> • Trends of snowpack loss, especially at lower and mid-elevations, and future shifts to more rain that affect the hydrologic regime are supported in the literature both in and outside the Uinta Mountains and Wasatch Range (six studies). • Changes in streamflow associated with climate change are supported by five studies. • Changes in the timing of runoff associated with climate change are supported by eight studies. • Historic drought and changes associated with climate change are supported by seven studies, and projections are based on both precipitation and temperature. • Historic flooding and future changes associated with climate change are supported by eight studies, and model projections have less agreement about precipitation than temperature. • The effects of hydrologic regime change on watershed function and biota are supported by six studies. 	

Hydrologic Regime

A snow-dominated hydrologic regime drives watershed processes in the Uinta Mountains and Wasatch Range. Lower elevations may have rain as well as snow melt influencing runoff. Although specific locations and elevations that are more influenced by rain than snow is an area of further study in the Uinta Mountains and Wasatch Range, the hydrologic regime is expected to shift to more rain. The shift has already been happening across the State of Utah since the 1970s. As a result, snow depth and snow cover have also been trending lower in the State (Gillies et al. 2012). The amount of snow varies from year to year since precipitation and temperature have natural variation. Increased winter precipitation can offset some effects of warming temperatures. However, Christensen and Lettenmaier (2007) projected Colorado River Basin runoff reductions, even with a modest increase in winter precipitation. The streamflow reductions ranged from 6 to 7 percent by mid-century as a result of temperature warming ranging from 5 to 8 °F (2.7 to 4.4 °C), snowpack loss, and increased evapotranspiration. Jones and Horell (2008) projected snowpack loss to be elevation-dependent in the Wasatch Range, from a 20 percent loss at the base and a 4 percent loss at the top of the Ben Lomond Range with a 1.8 °F (1 °C)

temperature increase. The Oquirrh Mountains southwest of Salt Lake City were projected to have a 16 percent loss at the base and 2 percent loss at the top with a 1.8 °F (1 °C) temperature increase (Jones and Horel 2008). By the mid-21st century, a transition from snow to more winter rain may also be more common in the Wasatch Range compared to the Uinta Mountains (see fig. 10 in Klos et al. 2014).

Streamflow is closely tied to the amount of winter snowpack and has had considerable variability over the past 500 years (Allen et al. 2013; Carson and Munroe 2005). Over the past century, however, there has been less variation in the Uinta Mountains and Wasatch Range. Observed streamflow from nine long-term streams in or adjacent to the Uinta-Wasatch-Cache and Ashley NFs show no statistically significant trend in annual runoff volume, while three stream gages on the west and south slope of the Uintas displayed statistically significant decreasing trends (fig. 28).

Streamflow (fig. 29) from neighboring stream gages showed a strong similarity to each other (R squared ≥ 0.84), especially streams with adjacent and similar headwaters like the Bear near the Utah-Wyoming State line. Weber and Provo had the strongest R squared values of 0.93 to 0.97 (see table D1 in Appendix D). These streams originate in the western Uintas within a few miles of each other. Streamflow on the north and south slopes of the Uintas was moderately similar among the gage sites with R squared values spanning 0.54 for Henry's Fork and Lakefork, while Bear and Lakefork had the highest R squared value of 0.79. Streamflow in the Wasatch Range was generally similar among the sites in the Wasatch Range (e.g., Big Cottonwood, Logan, and SF Ogden R squared ≥ 0.69) as well as with the western Uintas (e.g., Provo and Weber correlations with the Wasatch Range gages R squared was ≥ 0.77). Wasatch Range streamflows were not similar to streamflow draining the eastern Uintas (e.g., Henry's Fork, Ashley Creek, White Rocks compared with Logan or Ogden, R squared values ≤ 0.32). This demonstrates dissimilarities in both watershed characteristics and annual storm tracks between the eastern Uintas and areas west of there.

Changes in Streamflow

Streamflow will be influenced by increases or decreases in precipitation as well as warming temperatures that increase evapotranspiration and consequently decrease streamflow. In the Wasatch Range and western Uinta Mountains, the average decrease in annual runoff volume was projected to be approximately 4 percent per 1 °F of temperature warming (Bardsley et al. 2013). A synthesis of Colorado River Basin streamflow modeling studies by Vano et al. (2014) showed that across the different hydrologic models, the majority of them project decreased streamflow under climate change scenarios. Few model projections show streamflow increases associated with increased precipitation that offsets the effects of temperature warming, as modeled by Harding et al. (2012) in the Green River of the Upper Colorado River Basin. Variation of projected streamflows among the different studies was found to depend on the amount of temperature warming, changes in precipitation, and the type and method of the model used (Vano et al. 2014). The likely reductions in future streamflow are likely to be associated with varying reliability of the water supply in the southwestern United States (Rajagopal et al. 2014), with potentially unsustainable water deliveries for humans unless changes in water management are implemented (Barnett and Pierce 2009).

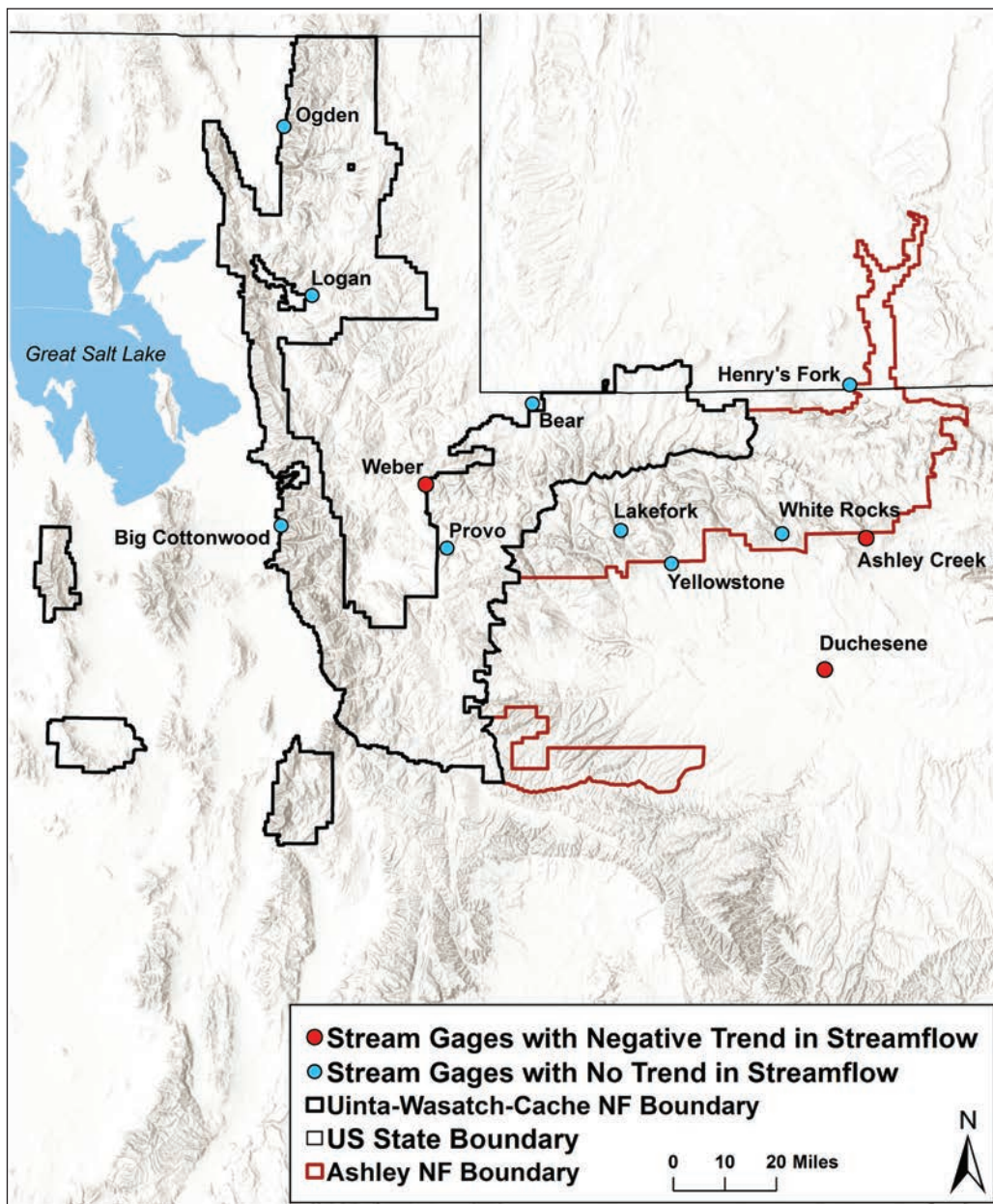


Figure 28—Twelve stream gage locations in the Wasatch Range and Uinta Mountains showing observed trends in streamflow for the water year October through September. Red marker indicates statistically significant decreasing streamflow, exceeding the 95% confidence level using a Mann-Kendall test. The Weber had a P -value of 0.025, the Duchesne P -value was 0.016, and Ashley Creek had a P -value of 0.012. Note: Most of these stream gages are in headwater areas with minimal impacts to natural flow, or in a few cases, locations where natural flow has been estimated. These gages have a minimum of 65 years of record with the longest record being 110 years. (Data source: U.S. Geological Survey. Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap, and the GIS user community.)



Figure 29—Streamflow (photo: Mark Muir, Ashley National Forest).

The different model studies project various changes in streamflow and water supply that are mostly reductions, and resolving the differences in streamflow projections and future precipitation is an area needing further scientific study. However, the scientific evidence points to certainty of warming temperatures that will reduce streamflow regardless of changes in precipitation (Vano et al. 2014).

Changes in Runoff Timing

Warmer temperatures and more rain instead of snow are expected to change flow regimes and runoff timing regardless of potential future changes in the total amount of precipitation. This has significant implications to ecosystems and water management. A shift to more rain has caused greater flow variation and more runoff during winter in the western United States (Ashfaq et al. 2013; McCabe and Clark 2005; Stewart et al. 2004, 2005). Also, peak flows are lower during spring and are shifted earlier with less snowpack and earlier melting (Stewart 2009). Several studies have noted recent trends in earlier snowmelt and more rain instead of snow that has caused the timing of stream runoff to shift up to 4 weeks earlier in the western United States (Clark 2010; Mote et al. 2005; Regonda et al. 2005; Stewart 2009; Stewart et al. 2005). A study by Bardsley et al. (2013) in the Wasatch and western Uinta Mountains projected the timing of the center of runoff, or the date when half of the water year runoff has occurred, would shift approximately 3 days earlier per 1 °F of temperature warming. This timing shift results in lower late-season flows and water availability, a time when human, agricultural, and ecologic needs are high.

Future Drought

Drought and drier conditions may become more intense and prolonged. Kunkel et al. (2013) projections had the mean annual maximum number of consecutive days with precipitation <0.1 inch (3 mm), increasing by 5 to 10 days per year in northern Utah by the mid-21st century. There was high climate model agreement (>67 percent) that this increase in dry days would occur. The duration and magnitude of future droughts are projected to be well outside the range of the observed historic record in the western United States. Cook et al. (2015) projected future drought for the southwestern U.S. region to significantly exceed the drought intensity during the Medieval Warm Period from 1100 to 1300 AD under both moderate and high climate-warming scenarios. Ault et al. (2014) projected the decade-long or mega-drought risk in the regional southwestern United States (including Utah) to increase from 45 percent over the last millennia to 70 and possibly 90 percent for the latter half of the 21st century. Multi-decadal drought risk was projected to increase from less than 1 percent or up to 50 percent across the southwest for the latter half of the 21st century. Gray and McCabe (2010) projected that for the Yellowstone River of Wyoming, extended droughts at their worst could reduce stream runoff to about one-half of the driest runoff levels in recorded history. The southwestern U.S. projections have variability in the magnitude of drought across the region, and mountainous areas may not have as pronounced drought effects as other areas in the southwest.

Future Flooding and Wet Periods

The future is likely to hold more intense flooding. As discussed in the “Sensitivity to Extreme Climatic Events (Drought, Heat, Floods)” section, flooding is the result of either unusually high accumulations of snowpack or extreme rainfall events (Bekker et al. 2014; Carson and Munroe 2005; Steenburgh et al. 2000). Flooding can also result from more rain instead of snow, or rain-on-snow events (Hamlet and Lettenmaier 2007), and be intensified in tributaries with large upslope contributing areas, in postfire watersheds, or in constrained canyons. An analysis of climate model projections by Kunkel et al. (2013) found that the number of days in a year with precipitation greater than 1 inch will increase in northeastern Utah, although less than 50 percent of the models making this projection agreed. As discussed in the “Climate of the Uinta-Wasatch-Cache and Ashley National Forests, Utah” section above, there is high model agreement (71 percent) that winters will become wetter in the Wasatch Range and Uinta Mountain. However, future flooding risk and the magnitude or timing of changes in precipitation is not clear.

Hydrologic Regime Changes and the Effects on Watershed Function

Hydrologic function and biota depend on the snow-driven hydrologic regime. They will be affected by future shifts to less streamflow and a more rain-driven hydrologic regime that will be most prominent at lower elevations as previously discussed in the “Climate of the Uinta-Wasatch-Cache and Ashley National Forests, Utah” section of this report. Flooding frequency and magnitude may increase in the future, affecting erosion processes and hindering biota. Stream channel size maintained by a flooding pulse from the peak spring snowmelt (Poff et al. 1997), and less snowpack, would reduce channel maintenance benefits. The spring snowmelt flood pulse depends on a

large area upstream being snow-dominated, an area that will be less snow-dominated as temperatures warm. Wetlands that are recharged by snowmelt could experience reduced water levels and more drying and desiccation (Winter 2000), especially late in the growing season. With less snowpack, it is possible that ephemeral streams will have shorter periods of streamflow with flashier patterns of inundation and drying. While this has been observed in the northeastern United States (Brooks 2009), and is likely to occur across Canada (Buttle et al. 2012), it is unknown if the U.S. Rocky Mountain ephemeral streams will react in a similar manner. Reynolds et al. (2015) modeling study in the upper Colorado River Basin projected more intermittent flows of perennial streams with climate change. Streams with low average flows and minimum flows with high variability were most susceptible to future streamflow intermittency. The shift from less snow to more rain could affect native trout that time their spawning with the spring snowmelt peak flow (Williams et al. 2009). The loss of snowpack associated with climate warming can also degrade and decrease the amount of stream habitat. Vegetation in forested areas depends on snowmelt through the spring and stored water in summer to support growth. Snowpack loss equates to less soil moisture availability, especially late in the growing season.

Watersheds in the Wasatch Range will likely have a very high vulnerability as their function and biota depend on the snow-driven hydrologic regime that is likely to shift to more rain. Uinta Mountain watersheds are projected to largely retain a snow-driven hydrologic regime, but watershed function will be affected by warming temperatures, thus a high vulnerability is assigned.

Potential for Climate Change to Exacerbate the Effects of Non-Climate Stressors, or Vice Versa

Summary	
Wasatch Range vulnerability: High	Uinta Mountain vulnerability: High
<ul style="list-style-type: none"> • Climate change and fire: Very high vulnerability is assigned as future warming, drying and snowpack loss can lengthen fire seasons and raise the fire potential across the Wasatch Range that already has a high risk for intense fire. More fire activity could reduce water quality and increase erosion and debris flow potential. 	<ul style="list-style-type: none"> • Climate Change and Fire: Moderate vulnerability is assigned as future warming, drying, and snowpack loss could raise the fire potential and lengthen fire seasons, but the majority of the Uinta Mountains currently have a low fire potential and low risk of intense fire activity. More fire associated with climate change could reduce water quality and increase erosion and debris flow potential.
<ul style="list-style-type: none"> • Climate change and bark beetles: Moderate vulnerability is assigned as warmer temperatures and drought that stresses trees raise the potential for bark beetle outbreaks. The host conifer trees in the Wasatch Range, however, do not extensively cover these mountains. 	<ul style="list-style-type: none"> • Climate change and bark beetles: High vulnerability is assigned as warmer temperatures and drought that stress trees raise the potential for bark beetle outbreaks in large areas of coniferous watersheds of the Uinta Mountains. Post-outbreak watersheds will likely have altered runoff, fire behavior, and stream chemistry, but changes such as these so far have been variable across the Rocky Mountains.

<ul style="list-style-type: none"> • Climate change and human water use: Very high vulnerability is assigned as climate warming and drying will further reduce and alter the timing of water availability that is in high demand for human uses. 	<ul style="list-style-type: none"> • Climate change and human water use: Very high vulnerability is assigned (see summary to left).
<ul style="list-style-type: none"> • Climate change and invasive species: High vulnerability is assigned as climate change can create new environments that would support invasive species whose spread may be promoted by human activity or fire disturbance. 	<ul style="list-style-type: none"> • Climate change and invasive species: High vulnerability is assigned (see summary to left).
<ul style="list-style-type: none"> • Climate change and air pollution: High vulnerability is assigned as warmer temperatures and drying that are expected with climate change have a high potential to exacerbate the effects of air pollution from urban and other sources. Ozone concentrations may increase with warmer temperatures. Particulate pollution may lower orographic precipitation. Dust-on-snow may contribute to earlier snowmelt and shift streamflow runoff timing. Nitrogen deposition may shift aquatic and terrestrial communities and increase the risk of oxygen depletion in high-elevation lakes. 	<ul style="list-style-type: none"> • Climate change and air pollution: As in the Wasatch Range, high vulnerability is assigned since warmer temperatures and drying that is expected with climate change have a high potential to exacerbate the effects of air pollution from surrounding land uses. Dust-on-snow may contribute to earlier snowmelt and runoff timing shift. High elevation lakes in the Uinta Mountains in particular may see nitrogen deposition shifting aquatic and terrestrial communities and increase the risk of oxygen depletion.
<ul style="list-style-type: none"> • Climate change and recreation: High vulnerability is assigned as recreation activity that degrades riparian areas, contributes pollution, increases erosion, and can lower water availability would be compounded by longer summer seasons that lengthen the amount of recreational activity that may shift to higher elevations. 	<ul style="list-style-type: none"> • Climate change and recreation: High vulnerability is assigned (see summary to left).
<ul style="list-style-type: none"> • Climate change and grazing: High vulnerability is assigned as climate warming, drought, and floods can intensify the effects of grazing that can degrade riparian areas, especially when not managed. 	<ul style="list-style-type: none"> • Climate change and grazing: High vulnerability is assigned (see summary to left).
<ul style="list-style-type: none"> • Climate change and roads and trails: High vulnerability is assigned as climate change can amplify the effects of roads and trails, increasing erosion, facilitating invasive spread, and altering drainage patterns in watersheds. 	<ul style="list-style-type: none"> • Climate change and roads and trails: High vulnerability is assigned (see summary to left). Also, in the Uinta Mountains, a large area is roadless wilderness, but trails still affect these areas.
<ul style="list-style-type: none"> • Climate change and energy development: High vulnerability is assigned as climate drying and warming lessen water available for energy development and other human uses. Oil and gas activities can also degrade air and water quality, which may be intensified with warming and drying. 	<ul style="list-style-type: none"> • Climate change and energy development: High vulnerability is assigned (see summary to left). Also, less snow cover during winter associated with climate warming can reduce the risk of high ozone levels.
<p>Summary of literature information depth supporting vulnerability: Climate interactions and the effect of non-climate stressors are well supported for fire (9 studies), bark beetle (17 studies), human water uses (11 studies), grazing (15 studies), energy development (7 studies), and air pollution (18 studies). Less literature was found linking climate change and non-climate stressors to invasives (5 studies), roads (5 studies), and recreation (5 studies). Also, orographic precipitation reductions caused by pollution have two supporting studies. Much of this literature is Rocky Mountain based.</p>	

Climate Change and Fire

Climate warming and drying has recently been observed to alter fire behavior. The last decade has seen lengthened fire seasons, more frequent fires larger than 1,000 acres (405 ha), and burned areas that were larger as compared to the 1970s and 1980s in the western United States (Dennison et al. 2014; Westerling et al. 2014). This upswing in fire activity has been attributed to warming, drying, earlier springs, and less snowpack (Westerling et al. 2014). Dillon et al. (2011) found a statistically increasing trend in the annual area burned and area burned severely between 1984 and 2006 in the southern Rocky Mountains (including the Wasatch Range and Uinta Mountains), the Mogollon Rim, and Colorado Plateau. The more important predictors of severe fire occurrence tended to be topographic variables, rather than climate or weather variables; however, when dry conditions prevailed, regional climatic controls appeared to overwhelm topographic variables (Dillon et al. 2011).

Fire risk potential for high intensity fire that may be difficult to suppress is mapped by the Fire Modeling Institute (fig. 30) and shows the highest risk of extreme fire behavior in the Wasatch Range and lower elevations surrounding the Uinta Mountains. Ager et al. (2014) modeled wildfire exposure to be higher in the Uinta-Wasatch-Cache NF than the Ashley NF. They incorporated the LANDFIRE (Landscape Fire and Resource Management Planning Tools) extreme fire potential, population density, departures from pre-European settlement conditions, vegetation conditions, and past fire behavior in their model. They found the higher probability of wildfire in the Uinta-Wasatch-Cache was a result of higher human populations in the Wildland Urban Interface. The Uinta-Wasatch-Cache NF was also one of the National Forests in the western United States modeled to have a highest probability of a “mega fire” greater than 50,000 acres (see fig. 6 in Ager et al. 2014).

Lengthened fire seasons in the western United States were projected by Yue et al. (2013), and Spracklen et al. (2009) projected the area burned in the Rocky Mountains would increase 154 percent by 2050 with a warmer and drier climate. Rocca et al. (2014) hypothesized that an increase in fire frequency was likely in the future and may result in a reduction of vegetation productivity such as piñon-juniper or lower montane trees. It also may eventually cause a lengthening of the fire return interval because less fuels are present on the landscape.

The potential intensification of fire activity associated with future climate change would hinder watershed function and degrade air and water quality. Goode et al. (2012) found the climate-driven increases in fire severity and extent have increased sediment yields in central Idaho, suggesting that the basin scale long-term average sediment yield of 146 T/km²/year may be exceeded in the next years or decades, impacting downstream reservoirs designed under lower sediment yields. Postfire hillslope conditions can have dramatic short-term effects on water quality (Luce et al. 2012), and air quality may also be degraded with more fire activity. Yue et al. (2013) projected a 46–70 percent increase in summertime surface organic carbon, or deposition of ash from fires, by mid-century. Given this, climate warming and drying has a moderate to very high potential to increase the frequency and size of fire and to lengthen fire seasons and hinder watershed function by increasing erosion and degrading water and air quality.

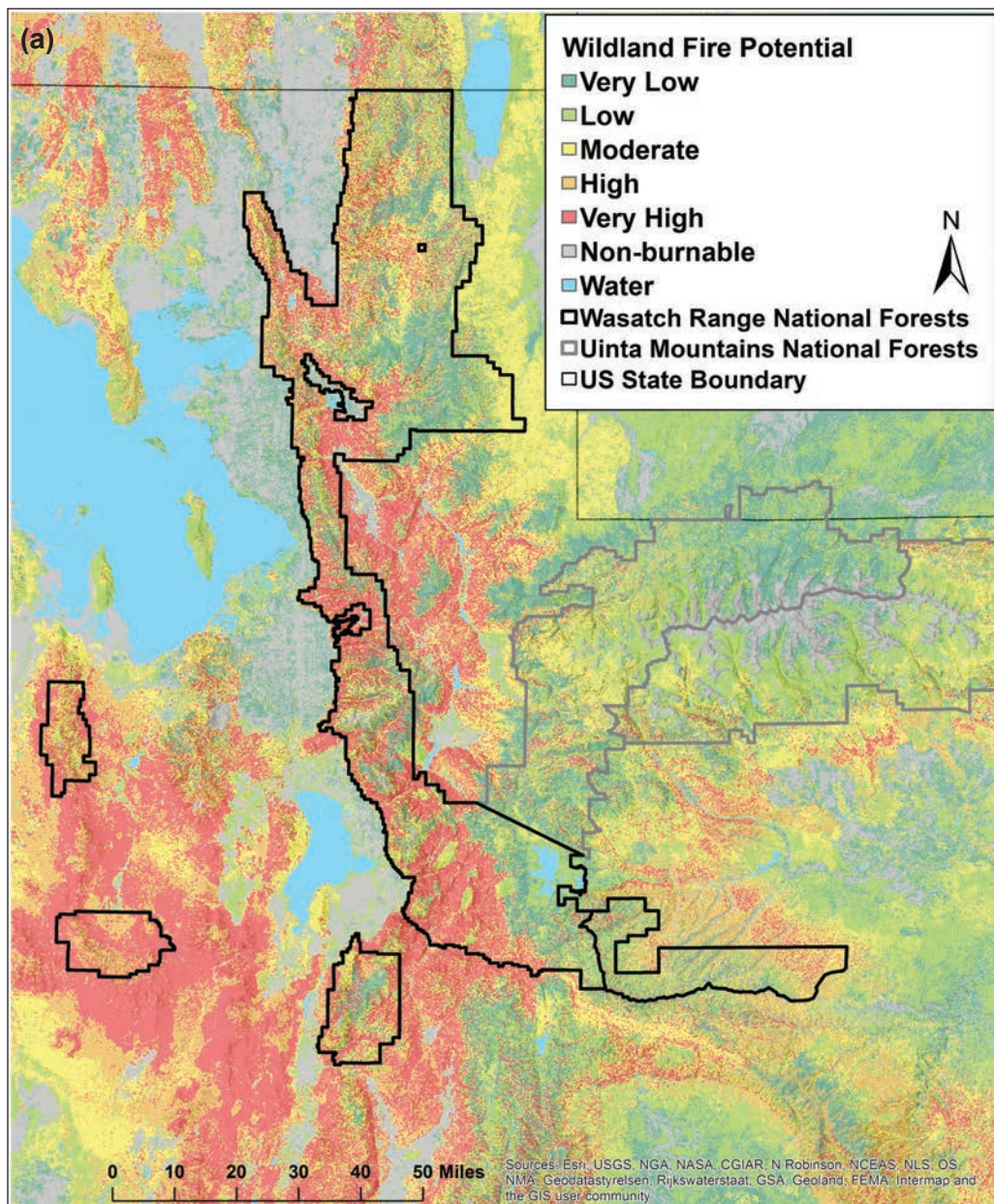
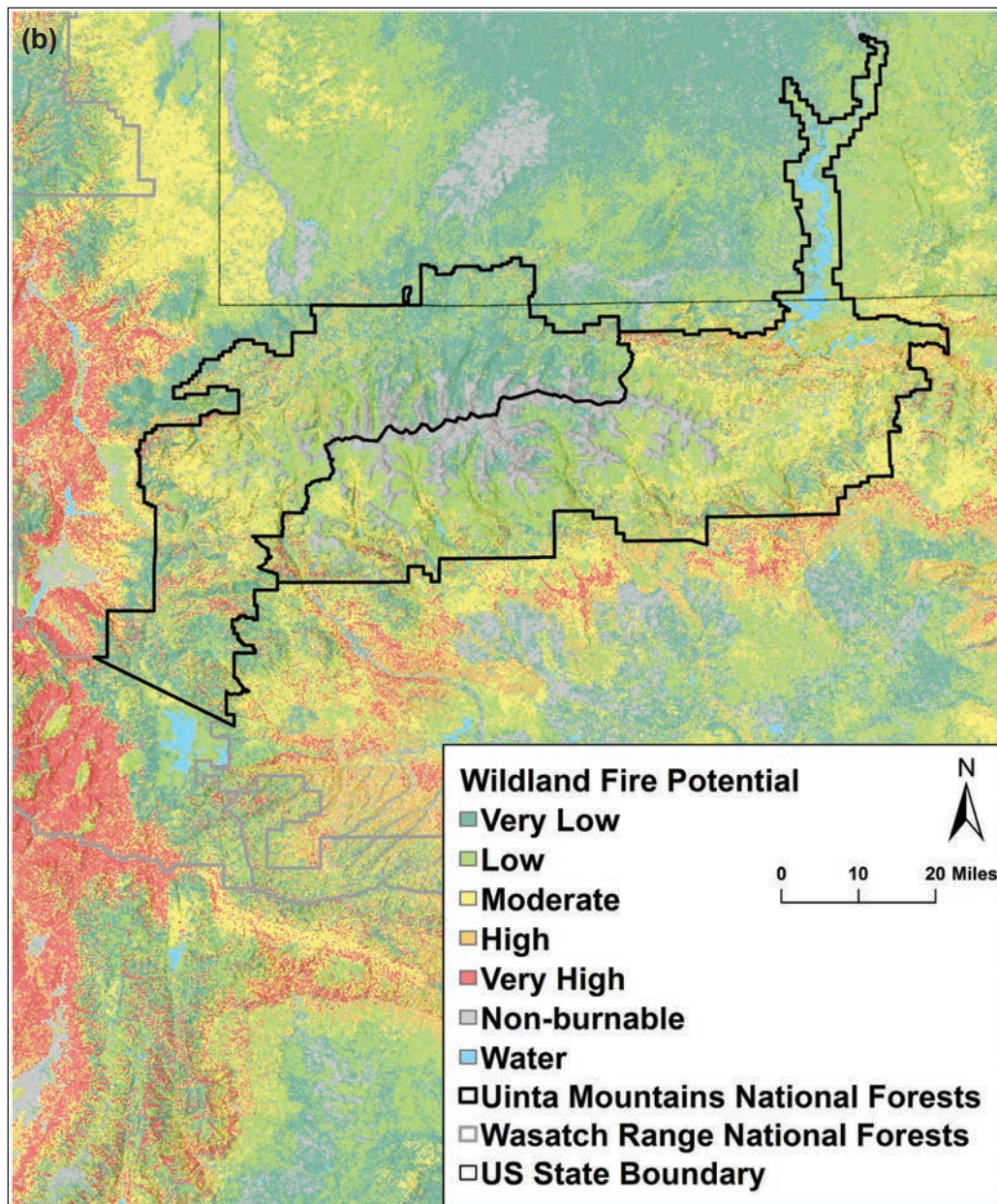


Figure 30—Wildland fire potential for the Wasatch Range (a) and Uinta Mountains and Flaming Gorge Reservoir (b). Higher fire potential indicates an elevated probability of experiencing high-intensity fire with torching, crowning, and other forms of extreme fire behavior under weather conditions conducive to fire (data from the Fire Modeling Institute (USFS 2013)).

Climate Change and Bark Beetle Outbreaks

Bark beetle outbreaks have affected many acres on National Forests and will likely continue to act as a damaging or mortality agent. Warmer temperatures and drought reduce the defensive mechanisms of trees and contribute to increased susceptibility to insect attacks that kill trees (Bentz 2009; Bentz et al. 2010; Mitton and Ferrenberg 2012). Bark beetles may expand their range to higher elevations as they track host trees that migrate to higher elevations and latitudes under climate change. A high spatial and temporal variation of outbreaks across the landscape is likely (Bentz 2009; Bentz et al. 2010).



While bark beetle outbreaks have caused large areas of tree mortality, the effects on water runoff have been variable. Some areas have seen increases in runoff. On the north slope of the Uintas, the water table has risen as large areas of beetle-killed lodgepole pine forests have resulted in less transpiration. In northwestern Colorado, increased runoff has been observed after bark beetle outbreaks during the mid-1940s (Bethlahmn 1974). In north-central Colorado, areas with recent extensive outbreaks, no changes in water yield, peak flows, or timing were observed Maggart (2014). While it is logical to assume runoff would increase after an extensive bark beetle outbreak, several factors contribute to the observed inconsistencies (Pugh and Gordon 2013). The interannual variability of precipitation makes it difficult to detect changes to streamflow that are likely caused by outbreaks (Lukas et al. 2014). MacDonald and Stednick (2003) and Stednick and Jensen (2007) noted that increases in streamflow after a bark beetle

outbreak or forest thinning were not seen in basins with annual precipitation below 20 inches per year. This resulted from increases in soil evaporation and understory growth water use taking up the available water left after tree mortality. Watershed topography, the amount of precipitation, soil type, forest structure and species composition, the rate of tree death, the extent of mortality, and size of area affected are also factors that contribute to observed inconsistencies in how bark beetle outbreaks affect runoff (Pugh and Gordon 2013).

Water quality impacts from nutrient loading or water chemistry changes after bark beetle outbreaks have been observed by initial field studies to be less than expected. No problems for human water use or aquatic systems was found in lodgepole pine forests affected by the 2000s mountain pine beetle outbreak in northcentral Colorado (Lukas and Gordon 2010). Nitrogen levels in streams have been observed to remain relatively unchanged in watersheds that underwent moderate to severe beetle outbreaks of lodgepole pine in the Colorado Front Range during the early 2000s (Rhoades et al. 2013).

The interactions between bark beetle outbreaks and fire is a subject of much debate. Jenkins et al. (2008) found both increases and decreases of fire intensity, extent, and severity after bark beetle outbreaks. They also found a high dependence of those changes on the spatial variability of fuel loads over time in western United States forests. In spruce-fir forests, fire, bark beetle disturbance history, topography, and drought can have variable effects on subsequent fire behavior (Bebi et al. 2003; Bigler et al. 2005; Kulakowski and Veblen 2007; Kulakowski et al. 2003). Hicke et al. (2012) synthesis of the contrasting bark beetle and fire studies found that bark beetle outbreaks do affect fuels and fire behavior, but there was the most disagreement in the literature about how the early post-outbreak stages affect fire. They assigned a lower confidence to findings about early stage outbreak and a higher confidence to late stage outbreak findings, as summarized below (Hicke et al. 2012).

Early stage after bark beetle outbreak (<4 years)

Less confidence

- Initial increase in crown fire potential.
- More surface fire activity potential with higher surface fuel loads.

Late stage after bark beetle outbreak (>4 years)

Higher confidence

- Ladder fuels increase from shrubs, seedlings, and coarse fuels from falling branches and snags.
- Lower crown fire potential as needles drop and fuels are concentrated closer to the surface, then a slow rise in crown fire potential over time.
- Surface and torching potential increases over time.

The effects of bark beetle outbreaks on watershed hydrologic function have been found to be variable. Regardless of how bark beetle outbreaks may affect runoff, water quality, or fire behavior in a given watershed, climate change has a moderate to high likelihood of exacerbating bark beetle outbreaks. This has already been observed with recent temperature warming and when tree defense mechanisms are reduced by drought stress.

Climate Change and Human Water Use

Human populations in the arid climate of northwestern Utah depend on water that flows from the Wasatch Range and Uinta Mountains. Water diversions and groundwater withdrawals—vital sources supporting municipalities and agriculture—number in the tens of thousands on the Uinta-Wasatch-Cache and Ashley NFs (UDOWR 2014b). In addition, the ski industry in the Wasatch Range uses water for snowmaking. The demand for water is likely to increase as populations expand (Bardsley et al. 2013; Foti et al. 2012). Higher populations and increased crop water use are projected in the Colorado River Basin (CWCB 2012), potentially reducing streamflow and affecting the ecologic and hydrologic function of watersheds. This increased demand for water risks the sustainability of the water supply, and when combined with a climate change effects that reduce water supply, the risk is even higher, as was modeled in the Colorado River Basin (Rajagopalan et al. 2009).

Climate warming and drying in combination with water withdrawals has ecological consequences for watersheds. These effects include less water for aquatic and riparian biota, less plant biodiversity, shifting riparian plant community compositions to less aquatic plant species, reduced channel size, lower sediment movement, nutrient transport modification, and changed stream chemistry (Caskey et al. 2014; Wohl 2006).

Reservoir construction and dam building may be a means to compensate for increased annual and seasonal variability in water availability, capturing rain or snow runoff when it is available (Viviroli et al. 2011). Dams also change the ecologic and hydrologic function of watersheds. They can modify discharge, reduce sediment transport, increase erosion and down cutting, narrow channels, alter the composition and abundance of aquatic and riparian communities, and increase the presence of invasive plants (Baker et al. 2011; Merritt and Wohl 2006; Wohl and Cenderelli 2000).

Given that there is likely to be an increasing human demand for water, there is a very high likelihood that climate warming and drying will exacerbate the effects of water withdrawals. These effects can change the hydrologic and ecologic function of watersheds.

Climate Change and Invasive or Non-Native Species

Watersheds in the Uinta Mountains and Wasatch Range are currently affected by several non-native aquatic, terrestrial, and riparian species. For example, non-native brown, brook, and rainbow trout compete with native fish. Non-native plants such as cheatgrass have encroached and replaced native species in some areas (fig. 31).

Non-native and invasive species living outside or near the Uinta-Wasatch-Cache and Ashley NFs have the potential to move into watersheds, altering species' interactions and disrupting ecosystem function (also see discussion on "Climate Change and Roads and Trails" below). Perennial pepperweed, saltcedar, leafy spurge, purple loosestrife, cheatgrass, spotted knapweed, and Canadian thistle have been particularly problematic in riparian areas of the interior Columbia and upper Missouri River basins (Al-Chokhachy et al. 2013). Spotted knapweed and Canadian thistle presence was correlated with higher road densities, and cheatgrass presence was correlated with fire (Al-Chokhachy et al. 2013).



Figure 31—Cheatgrass invasion on the Uinta-Wasatch-Cache National Forest (photo: Stacey Weems).

Aquatic invasive species in areas outside or near the Uinta-Wasatch-Cache and Ashley NFs are a threat to move into uninfested areas through human activity or stream networks. The non-native virile crayfish is an aquatic invasive species that can alter species' interactions and is near the Ashley NF. This crayfish has had an abrupt population increase since 2000 in the middle Yampa River of the Colorado Basin (Martinez 2012). The crayfish population growth coincides with a drought, and a population increase in another introduced species, smallmouth bass, which has likely caused over predation of juvenile native fishes (Martinez 2012). Other potential aquatic invasives are the quick-spreading zebra and quagga mussels. These mussels have the potential to move into aquatic systems through transport on recreational boats. These mollusks have been found in Lake Powell and the Navajo Reservoir, which is on the Colorado-New Mexico border (UDOWR 2014c).

How invasive species spread in the future and interact with climate is an area in need of further study. It is likely that at high elevations, the cooler conditions and lower productivity would hinder the spread of invasives, such as zebra or quagga mussels. Invasive riparian plant species, such as leafy spurge, have been projected to have a less invasion risk as a result of climate change, but cheatgrass, tamarisk, and Canada thistle are projected to have a greater invasion risk in lower elevation areas near or bordering the Uinta-Wasatch-Cache and Ashley NFs (see map in Bradley et al. 2009). Foothills desert communities may be overtaken by invasives like saltlover in the Ashley NF, a response that is already being observed under drought conditions. Saltlover has been found to alter soil chemistry and ecology, creating conditions more favorable to its persistence (Duda et al. 2003). Invasive species exist in the Uinta Mountains and Wasatch

Range, and other species have the potential to expand their distribution where suitable climate or environmental conditions develop. Human activities and travel corridors can promote the spread of invasive species, thus there is a high possibility of climate change exacerbating their spread.

Climate Change and Atmospheric Pollution

Ozone

Atmospheric pollution affects watersheds in the Uinta Mountains and Wasatch Range. Ozone, particulates, and dust, nutrients, and metals atmospheric deposition has been observed. Recent monitoring of ozone in the mountains of northeastern Utah and Colorado show concentrations have approached EPA exceedance levels (Korfmacher 2014; Musselman and Korfmacher 2014). In the Wasatch Range, urban pollution is carried into these mountains by prevailing winds, and they were found to have the highest ozone concentrations during summer (Korfmacher 2014). The low elevations of the Uinta Basin have peak ozone concentrations during winter when snow cover is present and temperature inversions and winter air mixing ratios favor ozone formation and persistence (Musselman and Korfmacher 2014). Peak ozone concentrations have been observed during spring and at nighttime in the southern Rocky Mountains, with highest concentrations at the highest elevations (Musselman and Korfmacher 2014). These high ozone levels can be caused by stratospheric intrusions, when turbulence from storm fronts passing through moves stratospheric ozone down toward the ground. High ozone levels pose a risk to vegetation by injuring leaves, reducing growth and yields, and making stressed plants more susceptible to disease, insects, and drought (Musselman et al. 2006). A study in the Wasatch Range suggested reduced Douglas-fir growth was the result of several factors and high ozone concentrations may have been one of the stressors reducing growth (Wager and Baker 2006). Ozone injury symptoms have been observed on ozone-sensitive plants in other areas of the Rocky Mountains; for example, cutleaf coneflower in Rocky Mountain National Park (Kohut et al. 2012). Korfmacher (2014) suggested that warmer and drier conditions could increase ozone concentrations above exceedance levels in areas near urban ozone production. This was also found by Jacob and Winner (2009) for areas near air pollution throughout North America, Europe, and Asia. Martin et al. (2015) projected that surface ozone would increase in the central and western United States National Parks and wilderness areas under the highest emission scenario and stringent domestic emission control standards, but surface ozone was reduced with a moderate climate scenario and stringent emission controls. Climate warming and drying increases atmospheric ozone.

The continued emissions of particulate air pollution could exacerbate the effects of climate warming and drying. Griffith et al. (2005) suggested that particulate air pollution from urban areas along the Wasatch Front has caused a decrease in winter orographic precipitation. Orographic precipitation is rain, snow, or other precipitation that falls when moist air is lifted as it moves over a mountain range. As the air rises and cools, orographic clouds form and serve as the source of the precipitation. In other areas of the western United States, air pollution has been linked to observed precipitation reductions near urban areas, and the precipitation reductions could not be explained by fluctuations in atmospheric circulation (Rosenfeld and Givati 2006).

Dust-on-Snow

Dust-on-snow events in the high elevations of the Rocky Mountains have been associated with human activity and drought in the Southwest (Steenburgh et al. 2012). Dust-on-snow is a loading of dust from downwind sources onto snowpack that increases the absorption of solar radiation, causing snow to melt faster. Carling et al. (2012) sampled snow before and after a dust event in the Wasatch Mountains and suggest that dust deposition provides the majority of trace and major elements and major anion loading in the Wasatch Mountains. This study measured increases in snowpack aluminum, arsenic, barium, calcium, cobalt, chromium, copper, iron, mercury, lithium, manganese, sodium, nickel, lead, antimony, strontium, titanium, thallium, uranium, vanadium, zinc, potassium, and magnesium. Major anions that were increased included: chlorine, nitrate, and sulfate. Southwestern Colorado has seen the highest dust loads on snow, which has quickened snowmelt and shifted the timing of runoff up to 3 weeks earlier (Painter et al. 2010). In the Uinta Mountains, these dust-on-snow events have been less intense than in southwestern Colorado, and it is unclear if runoff has been affected by dust-on-snow in the Uintas (Burgess 2014). In the Wasatch Range, dust events have been less frequent since the 1930s after the passage of the Taylor Grazing Act, but dust loading has been on an increasing trend in the Wasatch Front since the 1990s (Steenburgh et al. 2012). While more research is needed to determine if runoff has been shifted by dust loading in the Wasatch Range or Uinta Mountains, atmospheric dust loading has the potential to promote earlier snowpack melting and shift runoff earlier.

Atmospheric Deposition

Atmospheric deposition of nitrogen, phosphorus, and metals has increased since the late 1800s and are found in sediment cores of the high-elevation lakes of the Uinta Mountains (Hundey et al. 2014; Moser et al. 2010; Reynolds et al. 2010). Moser et al. (2010) measured increased lead, zinc, copper and cadmium. Reynolds et al. (2010) measured that after 1870, silver, arsenic, bismuth, cadmium, copper, indium, molybdenum, lead, antimony, tin, tellurium and the non-metallic element sulfur increased in lake sediment cores. The greatest increases in metal deposition have occurred after the early 20th century (Moser et al. 2010). This deposition has been associated with a shift in diatom composition to more metal-tolerant and nitrogen-loving species (Hundey et al. 2014; Moser et al. 2010). Temperature warming and drought could worsen the effects of atmospheric deposition by increasing algae growth, further changing water chemistry, increasing acidity, shifting species composition of phytoplankton communities, increasing algal production, and reducing biodiversity in terrestrial and aquatic ecosystems in the western United States (Hundey et al. 2014; Porter et al. 2013). As a result, high vulnerability is assigned.

Climate Change and Recreation

Outdoor recreation participation has increased during the early 2000s in the United States, with viewing natural scenery having the most participants, and kayaking, snowboarding, off-highway vehicle driving, and waterskiing activities increasing at least 30 percent (USDA Forest Service 2012). Per person outdoor recreation opportunities nationally are expected to decline since there is a stable public land base, a declining

private natural land base, and increased outdoor recreation participants (USDA Forest Service 2012). Participation in camping, fishing, hunting, nature viewing, hiking, swimming, boating, and winter activities are projected to greatly increase nationally, with the amount of future recreational activity determined by future population preferences and recreational opportunities that are available (USDA Forest Service 2012). Warmer temperatures and longer summer seasons could shift recreational activity to higher elevations, as has been observed on a global scale (Hamilton et al. 2005). It is already being observed that winter vehicle use of dirt roads is higher when there is a low snowpack or earlier snowmelt open roads, and moist soil conditions make roads more susceptible to rutting damage. The shifts in climate, longer summer seasons, and higher demands for recreation could increase the impacts on watersheds with more road building (see “Climate Change and Roads and Trails” section below). Winter recreation seasons across the western United States may be shortened, and snowmaking by ski resorts can mitigate the shortened seasons (Winton 2013). Snowmaking can lower water availability and winter streamflows (Pepin et al. 2002). Concentrated recreational use around streams can degrade riparian areas, compact soils, reduce water quality, and destabilize banks (Wohl 2006)—effects that have a high chance of being exacerbated by climate warming that lengthens summer seasons, allowing more recreational activity.

Climate Change and Grazing

Grazing on the Uinta-Wasatch-Cache and Ashley NFs is by wildlife and domestic livestock with alpine elevations also grazed by domestic sheep. Unregulated grazing during the early 20th century led to rangeland degradation and damage to watersheds in Emigration and Red Butte Canyons of the Wasatch Range (Cottam and Evans 1945). Grazing pressure was reduced when regulations were put into effect during the mid-20th century. More recently, the cattle numbers in Utah have been decreasing (–8 percent from 1997 to 2007) (Reeves and Mitchell 2012).

The effects of livestock grazing affect plant cover and soil conditions in watersheds to varying degrees. Neff et al. (2005) observed that a historically grazed area in southeastern Utah with cattle removed since 1974 had 34 to 48 percent lower soil silt compared to historically ungrazed areas. Fernandez et al. (2008) found that areas in southeastern Utah grazed by cattle had 20 percent less vegetation cover and 100 percent less soil organic carbon and nitrogen compared to sites grazed by native ungulates. Cattle grazing was found to lead to a clustered distribution of soil resources and increase erosion, causing more area with nutrient-depleted bare ground (Fernandez et al. 2008). However, grazing has not always been found to reduce vegetation cover. During the 1960s, moderate grazing intensity was observed to produce no changes in vegetation cover, production, or composition after 7 years in a sagebrush-grassland range in the Ashley NF that was in fair to good condition (Laycock and Conrad 1981). Crested wheatgrass and smooth brome seeded areas had an increase in production during a high precipitation year when grazed heavily during June on alternate years (Laycock and Conrad 1981).

Cattle grazing tends to be concentrated in riparian zones and around wetlands (Kauffman and Krueger 1984), and domestic sheep grazing tends to be concentrated at upland and hillslope sites. Heavy and prolonged sheep or cattle grazing can cause

adverse impacts to riparian areas in the Rocky Mountains (Platts 1981). Livestock grazing can reduce riparian vegetation, compact soils, increase erosion, alter riparian species communities, destabilize channels, widen channels, reduce water quality, lower water tables, reduce fish populations, and introduce noxious weeds (Armour et al. 1991; Kauffman and Krueger 1984; Wohl 2006). Knopf and Cannon (1982) found that heavy grazing in high-elevation riparian areas of northcentral Colorado during the early 20th century resulted in reduced shrub density and narrower riparian widths for several decades after grazing had been reduced. Studies investigating the effects of release from riparian grazing pressure in northeast Utah show greatly increased grass and willow cover, raised water tables, and improved fish habitat (Platts and Nelson 1985; Schulz and Leininger 1990). Hough-Snee et al. (2013) found that riparian herbaceous plants along a northern Utah stream recovered quickly, changing rapidly within 4 years after release from grazing, but woody riparian vegetation was slower to recover. Saunders and Fausch (2012) observed that in northern Colorado streams, both simple and intensive rotational grazing management of riparian areas resulted in more riparian vegetation, higher amounts of terrestrial invertebrates in trout diets, and higher biomass of fish compared to areas that had season-long grazing.

How climate change may exacerbate the effects of grazing will depend on several factors: grazing management, rangeland conditions, demand for grazing, and how forage production is affected by variations in the timing and amount of precipitation during the growing season. Climate change has a high potential of exacerbating the effects of grazing. Warmer temperatures can exacerbate the effects of grazing that reduce riparian vegetation and raise stream temperatures. More intense flooding can exacerbate the effects of increased erosion and destabilized stream banks. More drought can exacerbate the effects of grazing that lowers water tables. Climate change has a high potential of exacerbating the effects of grazing, but grazing management has the potential to offset these effects.

Climate Change and Roads and Trails

Roads and trails in the Uinta-Wasatch-Cache and Ashley NFs are widespread and a necessary means of conveyance for recreation, silvicultural, natural resource extraction, and other activities. The Watershed Condition Assessment (USDA 2013) classifies the condition of road and trail effects on watershed hydrology and sedimentation according to the density and distribution of roads and linear features within the watershed, classifying conditions as:

- The hydrologic regime is substantially intact and unaltered for 36 watersheds (Good).
- A moderate probability that the hydrologic regime is substantially altered for 110 watersheds (Fair).
- Higher probability that the hydrologic regime is substantially altered for 164 watersheds (Poor) (fig. 32).

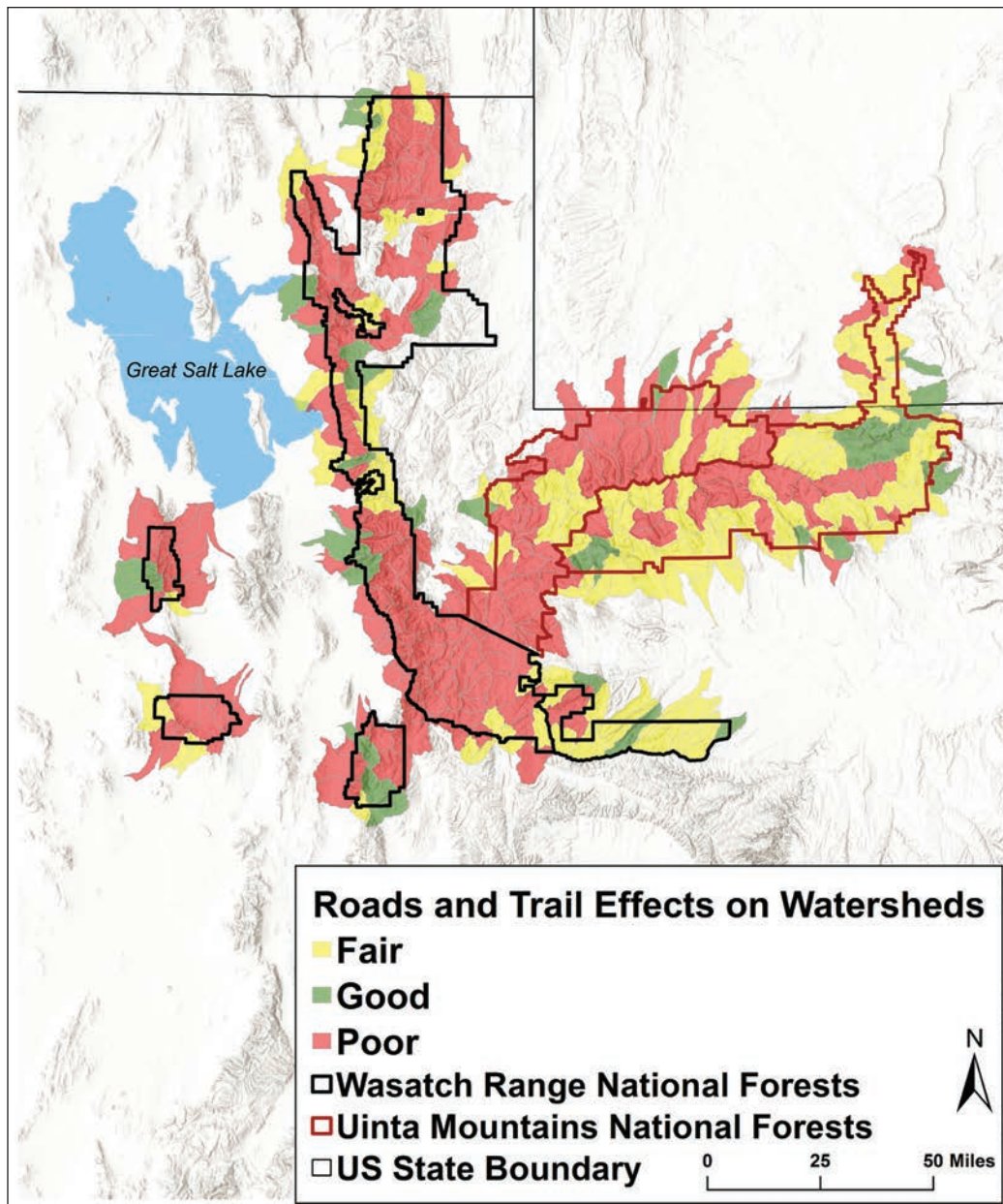


Figure 32—Road and trail effects on watershed hydrology and sedimentation classified according to the density and distribution of roads and linear features within the watershed indicate: that the hydrologic regime is substantially intact and unaltered (Good); a moderate probability that the hydrologic regime is substantially altered (Fair); or a higher probability that the hydrologic regime (timing, magnitude, duration, and spatial distribution of runoff flows) is substantially altered (Poor), U.S. Forest Service Watershed Condition Framework (USFS 2011). (Hillshade data credit: Esri, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community.)

In the United States, roads are sources of sediment and contaminants: they can alter drainage patterns in watersheds, increase surface runoff from soil compaction, intercept and divert water, lower aquatic species populations, alter riparian vegetation composition, increase heat, reduce soil moisture during the dry season from soil porosity changes, and facilitate the spread of invasive plants (Dauwalter et al. 2011; Pollnac et al. 2012; Trombulak and Frissell 2000). Best management practices can lower sediment and erosion and protect species, habitats, and water quality (Broadmeadow and Nisbet 2004). However, given that warming and drying and more intense flooding are likely in the future, there is a high chance warming and drying will exacerbate the road effect of reduced soil moisture and increased heat. More intense and frequent flooding will likely increase the effects of roads with a higher potential for surface runoff and erosion and altered drainage pattern.

Climate Change and Energy Development

The oil shale fields in Utah contain a vast and largely untapped resource that would help meet energy needs in the United States (Keiter et al. 2011). Utah could supply the United States with 25 percent of its oil needs over 85 years (Ruple and Keiter 2009). Development of these oil shale resources have seen boom and bust cycles over the past decades (Keiter et al. 2011). One factor controlling development is water availability, which is needed for shale processing. A boom in oil shale development could further tax scarce water resources, adding competition for municipal, agricultural, and other users (Ruple and Keiter 2009).

Oil shale development can also pose environmental risks to air and water quality, habitats, and species (Brittingham et al. 2014; Dauwalter 2013). In the Uinta Basin, oil and gas production has been associated with ozone concentrations that exceed levels harmful to human health during cold periods when the ground is covered with snow (Edwards et al. 2013). The winter of 2011 to 2012 was a snow-free season and without elevated ozone concentration (Ahmadov et al. 2015; Edwards et al. 2013). This suggests that climate warming leading to snow-free winters in the Uinta Basin may avert elevated ozone concentrations. However, other pollutants such as volatile organic compounds are emitted from oil and gas activity (Warneke et al. 2014), which degrade air quality. Further study is needed to define how climate change may affect air pollution associated with oil and gas production.

While it is not entirely clear how the effects of air pollution from oil and gas activity may interact with climate change, the water needs and environmental risks of energy development are activities that will likely exacerbate the effects of climate change. Drought would further limit water availability, and warmer temperatures and drier conditions have the potential to exacerbate the effects of air and water quality degradation.

Likelihood of Managing or Alleviating Climate Change Effects

Summary	
Wasatch Range vulnerability: High	Uinta Mountain vulnerability: High
<ul style="list-style-type: none"> High vulnerability is assigned as management activities exist to reduce stressors but are untested as to the effectiveness in reducing the effects of future climate change on watersheds, and they may not be completely effective in offsetting climate change and human-caused stressors. Sometimes management activities may be overwhelmed by the changes in climate that intensify drought, snowpack loss, heat, flooding, fire, or other disturbance. The mitigating effects of management actions may also be overwhelmed by human caused stressors to watersheds from water diversions, air pollution, recreation, roads, and grazing. 	<ul style="list-style-type: none"> High vulnerability is assigned (see summary to left).
Summary of literature information depth supporting vulnerability: <ul style="list-style-type: none"> Numerous watershed management activities have been well documented and tested throughout the United States on National Forests for mitigating stressors and building resilience of watersheds, but these management actions have not been measured for effectiveness in mitigating future climate change effects. Two watershed management documents are included that were written by Forest Service scientists, and five other supporting examples are included. This information is for other areas of the United States and no direct examples for the Uinta-Wasatch-Cache and Ashley NFs are included. 	

Adaptation to climate change is a complex challenge, and a new and growing body of science has developed to support and guide adaptation to climate change (Moss et al. 2013). Developing and implementing climate-adaptation options face the challenges of: limited financial resources available for management activity, conflicting social and political values and policy direction, and limited or unclear information to guide adaptation option development, such as multiple trajectories of future climate.

Identifying the success of climate-adaptation actions is an area in need of further scientific study. Success is defined by achieving multiple objectives from economic, institutional policy, ecological, social, and political viewpoints (Moser and Boykolf 2013). Doria et al. (2009) used expert elicitation to define successful adaptation to climate change as “any adjustment that reduces the risks associated with climate change, or vulnerability to climate change impacts, to a predetermined level, without compromising economic, social, and environmental sustainability” (fig. 33). Few examples of successful climate change adaptation exist, while adaptation to past climate or non-climate stressors are numerous (Moser and Boykolf 2013).

A large amount of information is available on watershed and forest management with varying degrees of success and effectiveness. For example, bark beetle treatments have been shown to reduce tree mortality in small outbreaks, but not in large areas of epidemic outbreaks (Black et al. 2013). Fuel reduction treatments have succeeded in reducing fire intensity and severity (Martinson and Omi 2013), but sometimes they have



Figure 33—Managed stream in watershed on the Ashley National Forest (photo: Mark Muir, Ashley National Forest).

been overwhelmed by extreme weather conditions (Graham 2003; Graham et al. 2012). Development, such as water diversions or inter-basin transfers, can have negative ecologic effects (Carlisle et al. 2014; Meador 1992), putting challenges on the feasibility or effectiveness of management such as aquatic habitat restoration. While the effectiveness of climate-adaptation management actions is an area of further study, numerous watershed management actions have been used to protect, maintain, and restore watersheds, increasing their resilience to climate change and other stressors (Furniss et al. 2010; Rieman and Isaak 2010). These actions can either conserve existing species and habitats by focusing on developing resistance and resilience, or facilitate transitions to new states that would be desirable in the future (Millar et al. 2007; Furniss et al. 2010; Rieman and Isaak 2010). Management actions have the potential to lessen the effects of climate change on watersheds (summarized in table 9). Management actions need consideration of management goals, as well as an evaluation of effectiveness, and may need to apply methods in innovative ways to meet new challenges of future climate change (Bierbaum et al. 2013; Mawdsley et al. 2009). Despite the challenges of climate adaptation, there is a strong call to develop climate adaptation science and implement actions that mitigate climate change (Moss et al. 2013). Climate adaptation is an iterative process that requires long-term planning and monitoring.

Table 9—Summary of management activities that can reduce stressors and the effects of climate change (information from Furniss et al. 2010 and Rieman and Isaak 2010 unless otherwise cited in the table).

Adaptation objective	Management action	Benefit	Examples	Considerations
Increase resilience and resistance to drought	Maintain and restore stream flow and the natural hydrologic regime	Increases instream flow and maintains aquatic habitat during drought	<ul style="list-style-type: none"> • Facilitate cooperative, coordinated efforts among water users for withdrawal • Develop water releases that mimic natural flow when possible • Limit groundwater withdrawals • Silvicultural treatments to enhance water infiltration • Build flexibility into permits to allow for changes in hydrology and climate • Increase and strategically place natural structures in watersheds to promote the retention of water (TNC 2012) 	Human water needs vs. ecological needs Costs of silvicultural or other activity
	Reintroduce beaver	<ul style="list-style-type: none"> • Promotes water retention • Increases complexity of aquatic habitat • Supports aquatic and riparian biota 	<ul style="list-style-type: none"> • Introduce beaver in areas where appropriate 	<ul style="list-style-type: none"> • Creating barrier to fish passage • Riparian vegetation removal
Increase resilience and resistance to heat	Enhance or expand riparian vegetation	<ul style="list-style-type: none"> • Shading mitigates stream temperature warming • Increases the capacity to filter pollution • Supports aquatic species and wetlands 	<ul style="list-style-type: none"> • Reduce grazing pressure or practice grass banking (Schumann 2013; TNC 2013) • Protect sensitive areas (wetlands, fens) • Planting, seeding 	<ul style="list-style-type: none"> • Economic costs of fewer grazing opportunities and the possibility of increasing off-Forest land pressure <p>(continued)</p>

Adaptation objective	Management action	Benefit	Examples	Considerations
Increase resilience and resistance to floods	Restore or expand riparian and upland vegetation	<ul style="list-style-type: none"> • Reduces erosion • Stabilizes stream banks and hill-slopes • Water retention by vegetation buffers the effects of flooding 	<ul style="list-style-type: none"> • Planting, seeding • Protect sensitive riparian areas (wetlands, fens) 	
	Lower fire risk and mitigate the effects of fire	<ul style="list-style-type: none"> • Reduces damage to vegetation that can buffer flooding impacts • Reduces erosion 	<ul style="list-style-type: none"> • Fuel treatments—thinning or prescribed fire 	Cost vs. benefit
	Create structures that reduce the effects of flooding	<ul style="list-style-type: none"> • Stabilizes hillslopes and reduces erosion 	<ul style="list-style-type: none"> • Check dams 	
	Reduce the impacts of infrastructure	<ul style="list-style-type: none"> • Reduces erosion and damage from flooding 	<ul style="list-style-type: none"> • Disconnect roads from drainage networks or stormproof roads (Keller and Ketcheson 2011) • Design and build infrastructure with higher safety factors 	
Increase the resilience and resistance of biota	Increase aquatic and biologic connectivity	Supports populations and connectivity of habitats	<ul style="list-style-type: none"> • Maintain or create a larger network of habitat • Design structures to allow free passage of wood, sediment, and aquatic biota. For example, fish passage structures (Bunt et al. 2012) 	
	Reduce or limit stressors	Supports healthy aquatic, riparian, and hydrologic function	<ul style="list-style-type: none"> • Limit recreational or other activity in sensitive areas • Stormproof roads or decommission them to reduce erosion and restore natural flow paths • Eliminate or reduce contaminants • Treatments to reduce or eliminate invasives • Use of prescribed fire or silvicultural treatments to reduce fire severity and maintain resilient vegetation communities 	Human uses vs. ecologic benefits

(continued)

Adaptation objective	Management action	Benefit	Examples	Considerations
Facilitate transitions to new states	Transport species to areas with suitable climate and environmental conditions	Adds ecologic function and value	<ul style="list-style-type: none"> • Transport individuals to inaccessible habitats or places of refuge to maintain genetic variety • Remove barriers to allow species to migrate where possible • Allow new species to colonize areas where other species can no longer survive 	
Develop local information	Monitor to identify trends in species' populations, air, soil, water quality and changes in flow regimes	Enables a better understanding of how climate and other factors affect watershed processes	<ul style="list-style-type: none"> • Vegetation, fish, insect, bird, and mammal surveys • Air, soil, water quality, stream temperature monitoring • Streamflow, snow, groundwater monitoring 	Cost, benefit, and statistical credibility of data (Caughlin and Oakley 2001)
Collaborate	Coalition building	Promotes common understanding and goals for watersheds, and promotes a capacity for response that includes all stakeholders and is based on science	<ul style="list-style-type: none"> • Internal collaboration across disciplines to design and implement projects • Engage stakeholders, build and maintain collaborative relationships 	Requires a commitment to communication

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Appendix A—Climate Model Projections (Coupled Model Intercomparison Project Phase 5).

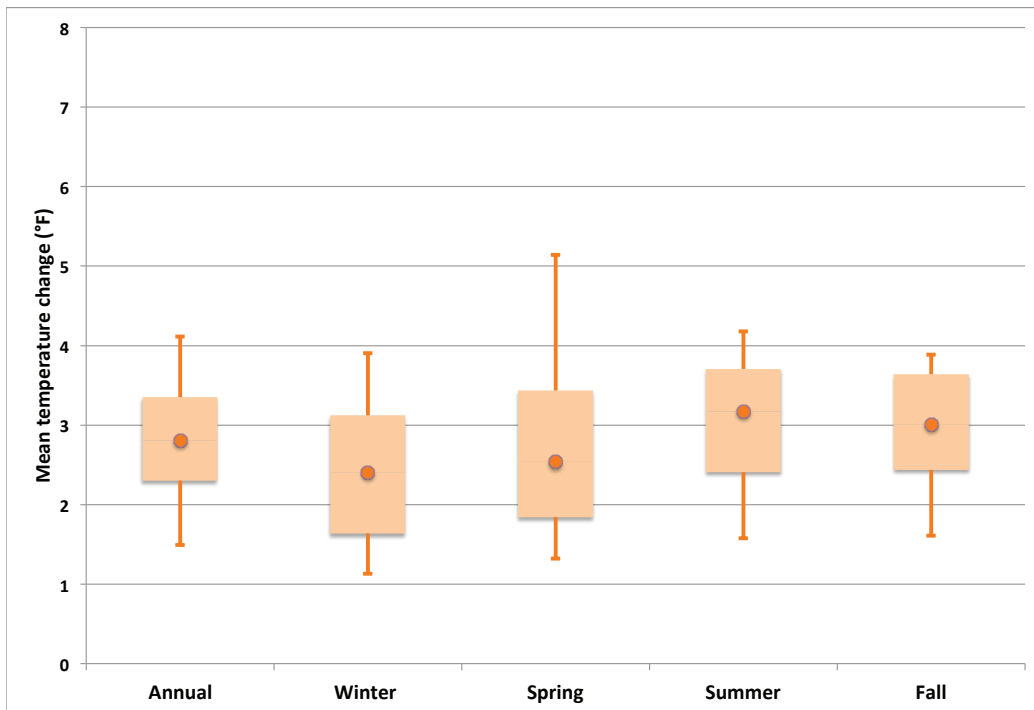


Figure A1—Annual and seasonal temperature change projections for 2035–2064 relative to 1981–2010 for the Representative Concentration Pathway (RCP) 2.6. There are 53 model runs included in this projection (Reclamation 2014).

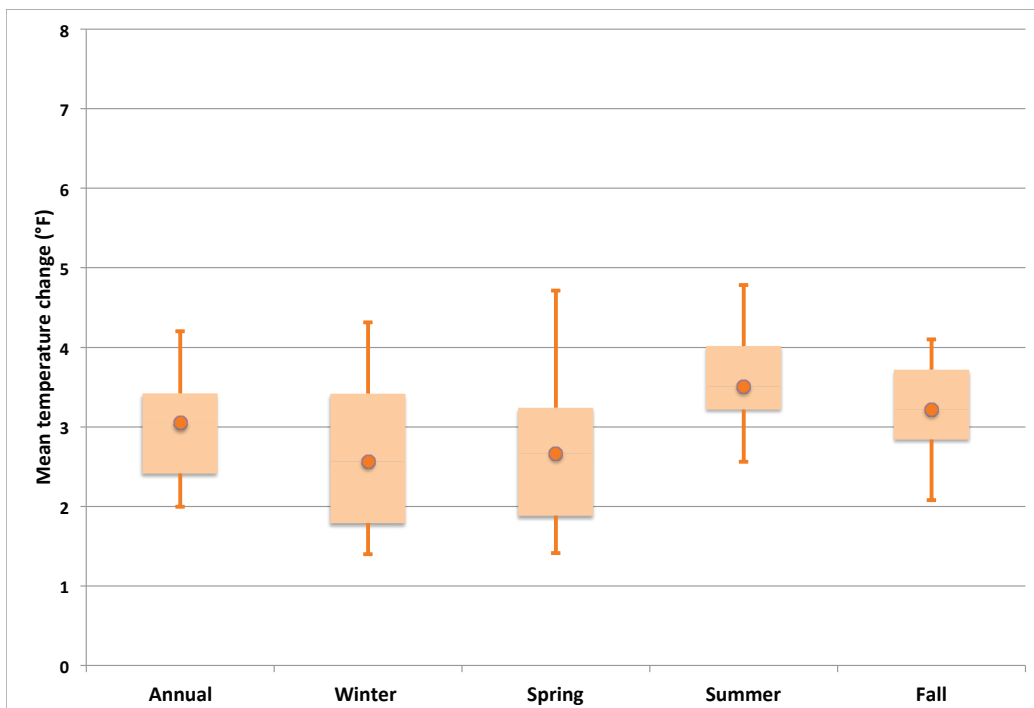


Figure A2—Annual and seasonal temperature change projections for 2035–2064 relative to 1981–2010 for the Representative Concentration Pathway (RCP) 6.0. There are 37 model runs included in this projection. Reclamation (2014).

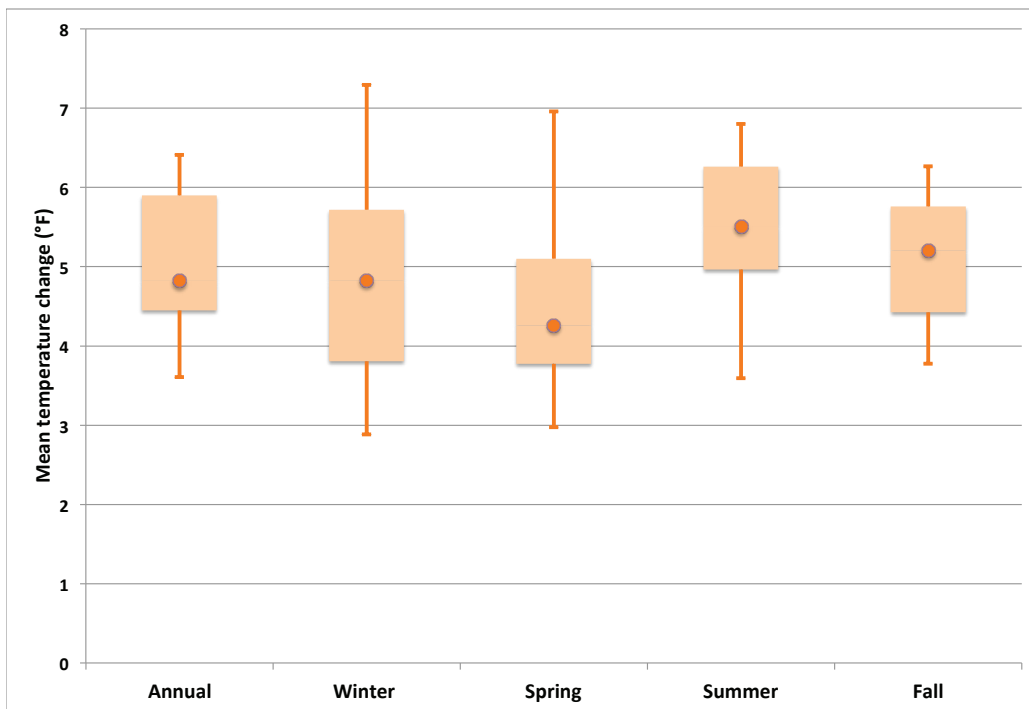


Figure A3—Annual and seasonal temperature change projections for 2035–2064 relative to 1981–2010 for the Representative Concentration Pathway (RCP) 8.5. There are 70 model runs included in this projection. Reclamation (2014).

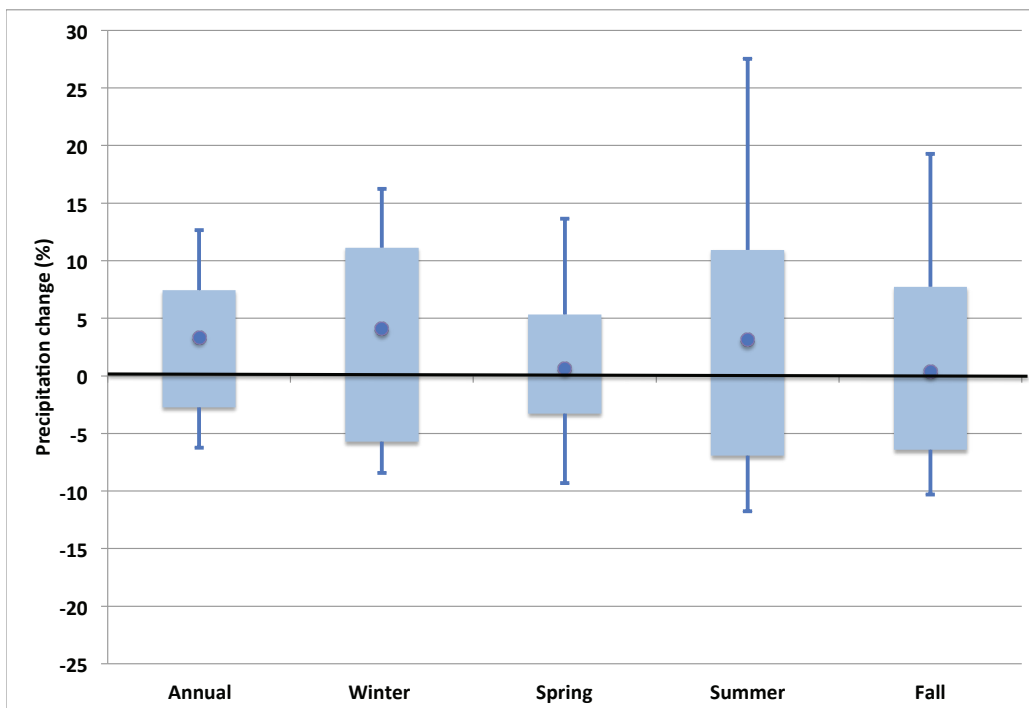


Figure A4—Annual and seasonal precipitation percent change projection for 2035–2064 relative to 1981–2010 for the Representative Concentration Pathway (RCP) 2.6. There are 53 model runs included in this projection. Reclamation (2014).

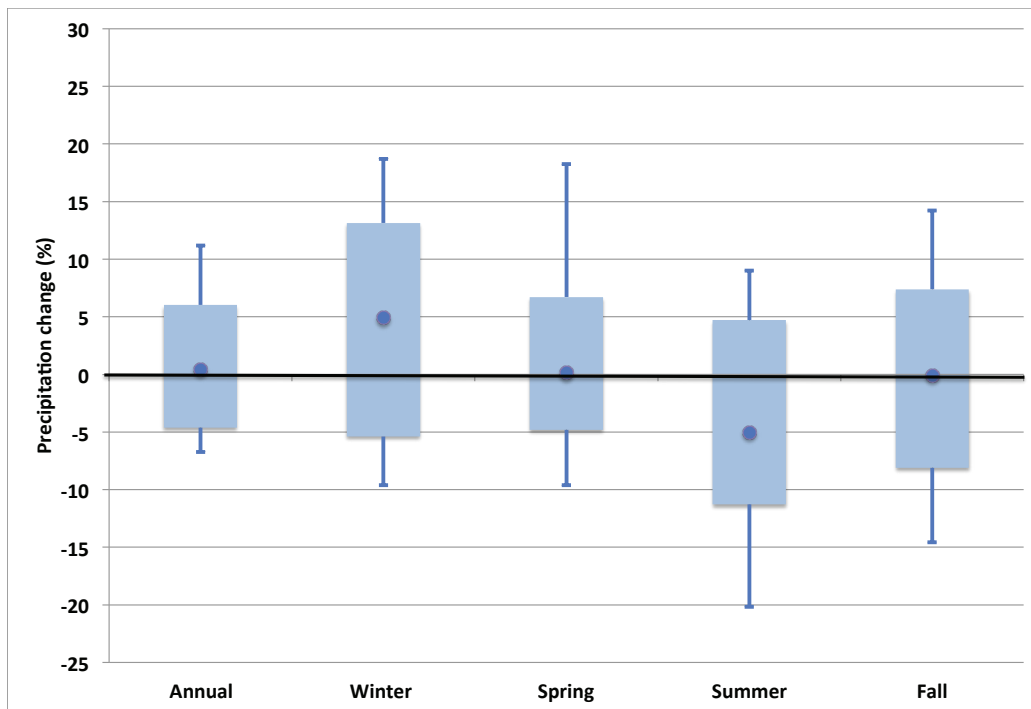


Figure A5—Annual and seasonal precipitation percent change projection for 2035–2064 relative to 1981–2010 for the Representative Concentration Pathway (RCP) 6.0. There are 37 model runs included in this projection. Reclamation (2014).

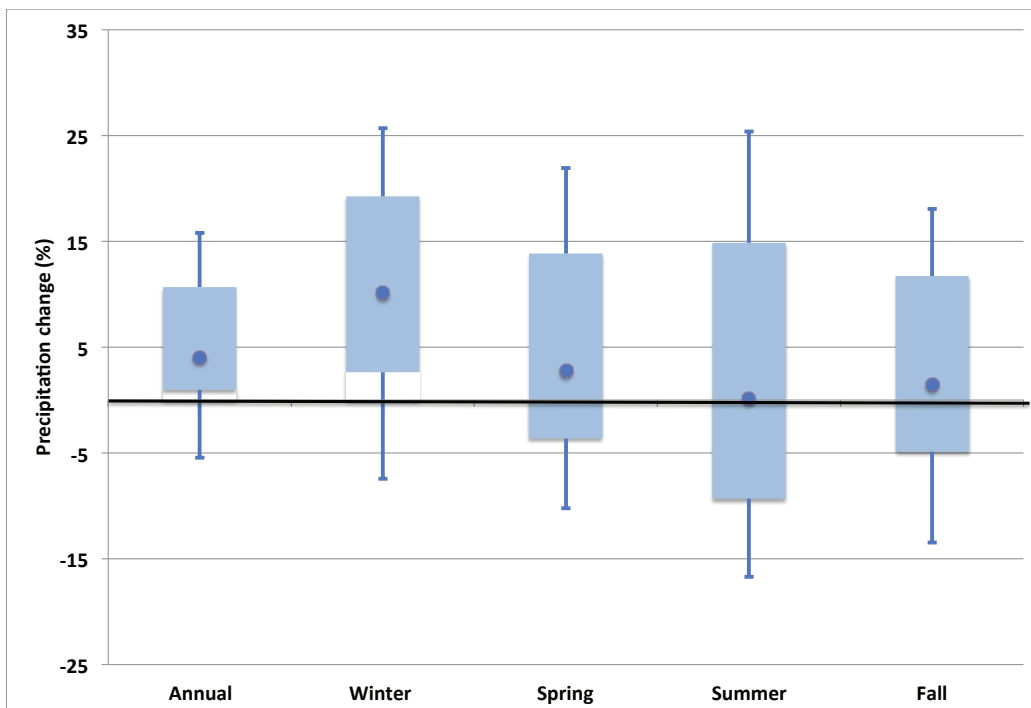


Figure A6—Annual and seasonal precipitation percent change projection for 2035–2064 relative to 1981–2010 for the Representative Concentration Pathway (RCP) 8.5. There are 70 model runs included in this RCP projection. Reclamation (2014).

Table A1—Projected changes in temperature and precipitation from 1981–2010 to 2035–2064 for northeastern Utah Climate Division 5, combined for 231 model runs of RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5. See figures 6 and 7 for graphs of projections of RCP 4.5 that are not graphed below.

Projected changes by 2035–2064 ^a	Mean	10th	50th	90th
Change in annual average temperature (°F)	3.8	2.2	3.7	5.8
Change in annual average precipitation (%)	4.0	-6.0	3.1	14.4

^a Projections are based on 231 model runs from 1/8° CMIP5 BCSD (bias-correction and spatial disaggregation) including all Representative Concentration Pathways (RCPs). See Appendix C for Models. Accessed from Reclamation 2014.

Appendix B—Watershed Vulnerability Assessment Development Process and Scoring Details

Watershed Vulnerability Assessment Development Process

The information in this literature-based vulnerability assessment involved three sets of reviews to vet the structure and content of the information:

- A first draft was compiled based on searches for literature relevant to the seven vulnerability criteria for watersheds, and information was interpreted and synthesized to pull out key points relevant to the vulnerability criteria. This draft was reviewed by the Uinta-Wasatch-Cache and Ashley NF staff. Suggestions for structuring the information in the assessment were implemented in a second draft.
- The second draft was reviewed by five experts. Suggestions for clarifications and additions of scientific information, as well as their assessment of vulnerability scores for each criteria, were incorporated in a third draft.
- A workshop with National Forest managers was held, in which key points for watershed processes and species were presented and potential management actions were discussed.
- The third draft was reviewed by the Uinta-Wasatch-Cache and Ashley NF staff before submission to publication.

Watershed Vulnerability Scoring Details

Climate change vulnerability across the indicators spanned from moderate to high (table B1). Sensitivity to extreme climatic events, dependence on a specific hydrologic condition, and the potential for climate change to exacerbate the effects of non-climate stressors have high vulnerability, while all other criteria have a moderate rating. The range of vulnerability spans from low to very high and the overall average of these criteria is in the high category for the Wasatch Range and ranges in the moderate to high category for the Uinta Mountains. Four expert reviewers provided confidence in vulnerability rankings, which averaged moderate.

Table B1—Wasatch Range and Uinta Mountain vulnerability score by criterion, the overall vulnerability score, and the mean confidence of expert reviewers.

Vulnerability criterion	Wasatch Range vulnerability	Uinta Mountain vulnerability	Mean confidence of expert reviewers
Range shift capacity	High	Moderate	Moderate
Vulnerability of cold-adapted, foundation, or keystone species	Low to very high	Low to very high	High
Sensitivity to extreme climatic events	High to very high	Moderate to very high	High
Intrinsic adaptive capacity	Moderate	Moderate	Moderate
Dependence on specific hydrologic condition	Very high	High	Moderate
Potential for climate change to exacerbate the effects of non-climate stressors, or vice versa	High	High	Moderate
Likelihood of managing or alleviating climate change effects'	High	High	Low
Overall vulnerability	High	Moderate to high	Moderate confidence

Appendix C—Coupled Model Intercomparison Project Phase 5

Modeling Groups

We acknowledge the World Climate Research Programme's Working Group on Coupled Modeling, which is responsible for CMIP, and we thank the climate-modeling groups (listed in table C1) for producing and making available their model output from 62 models. For CMIP, the U.S. Department of Energy's Program for Climate Model Diagnosis and Intercomparison provides coordinating support and led development of software infrastructure in partnership with the Global Organization for Earth System Science Portals.

Table C1— Climate modeling groups for CMIP5.

Modeling center (or group)	Institute ID	Model name
Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia	CSIRO-BOM	ACCESS1.0 ACCESS1.3
Beijing Climate Center, China Meteorological Administration	BCC	BCC-CSM1.1 BCC-CSM1.1(m)
Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research)	INPE	BESM OA 2.3 ^a
College of Global Change and Earth System Science, Beijing Normal University	GCESS	BNU-ESM
Canadian Centre for Climate Modelling and Analysis	CCCMA	CanESM2 CanCM4 CanAM4
University of Miami - RSMAS	RSMAS	CCSM4(RSMAS)
National Center for Atmospheric Research	NCAR	CCSM4
Community Earth System Model Contributors	NSF-DOE-NCAR	CESM1(BGC) CESM1(CAM5) CESM1(CAM5.1,FV2) CESM1(FASTCHEM) CESM1(WACCM)
Center for Ocean-Land-Atmosphere Studies and National Centers for Environmental Prediction	COLA and NCEP	CFSv2-2011
Centro Euro-Mediterraneo per I Cambiamenti Climatici	CMCC	CMCC-CESM CMCC-CM CMCC-CMS
Centre National de Recherches Météorologiques / Centre Européen de Recherche et Formation Avancée en Calcul Scientifique	CNRM-CERFACS	CNRM-CM5 CNRM-CM5-2
Commonwealth Scientific and Industrial Research Organization in collaboration with Queensland Climate Change Centre of Excellence	CSIRO-QCCCE	CSIRO-Mk3.6.0
EC-EARTH consortium	EC-EARTH	EC-EARTH
LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences and CESS, Tsinghua University	LASG-CESS	FGOALS-g2

LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	LASG-IAP	FGOALS-gl FGOALS-s2
The First Institute of Oceanography, SOA, China	FIO	FIO-ESM
NASA Global Modeling and Assimilation Office	NASA GMAO	GEOS-5
NOAA Geophysical Fluid Dynamics Laboratory	NOAA GFDL	GFDL-CM2.1 GFDL-CM3 GFDL-ESM2G GFDL-ESM2M GFDL-HIRAM-C180 GFDL-HIRAM-C360
NASA Goddard Institute for Space Studies	NASA GISS	GISS-E2-H GISS-E2-H-CC GISS-E2-R GISS-E2-R-CC
National Institute of Meteorological Research/Korea Meteorological Administration	NIMR/KMA	HadGEM2-AO
Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	MOHC (additional realizations by INPE)	HadCM3 HadGEM2-CC HadGEM2-ES HadGEM2-A
Institute for Numerical Mathematics	INM	INM-CM4
Institut Pierre-Simon Laplace	IPSL	IPSL-CM5A-LR IPSL-CM5A-MR IPSL-CM5B-LR
Japan Agency for Marine-Earth Science and Technology, Atmosphere, and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	MIROC	MIROC-ESM MIROC-ESM-CHEM
Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	MIROC	MIROC4h MIROC5
Max-Planck-Institut für Meteorologie (Max Planck Institute for Meteorology)	MPI-M	MPI-ESM-MR MPI-ESM-LR MPI-ESM-P
Meteorological Research Institute	MRI	MRI-AGCM3.2H MRI-AGCM3.2S MRI-CGCM3 MRI-ESM1
Nonhydrostatic Icosahedral Atmospheric Model Group	NICAM	NICAM.09
Norwegian Climate Centre	NCC	NorESM1-M NorESM1-ME

^a Model output not yet available.

Appendix D—Streamflow Correlation Analysis

Gage site streamflow correlations are listed in table D1.

Table D1—Correlations between pairs of long-term stream gage locations near the Uinta-Wasatch-Cache and Ashley National Forests. Numeric values indicated in the matrix are R squared. *Indicates calculated naturalized flow estimate. **Indicates gage has known impact to natural flow that was not compensated for.

Site name (abbreviation)		Period of record	LR	SFO	WO	PW	BC	BR	HF	LK	YR	WR	DR	AC	Elevation (feet)
Logan (LR)*		1922–2014	na	0.91	0.77	0.78	0.69	0.69	0.30	0.51	0.44	0.28	0.50	0.23	4680
SF Ogden (SFO)		1922–2014	0.91	na	0.82	0.83	0.75	0.71	0.32	0.54	0.50	0.32	0.58	0.29	5190
Weber (WO)		1905–2014	0.77	0.82	na	0.97	0.85	0.93	0.48	0.75	0.67	0.53	0.77	0.54	6640
Provo (PW)*		1950–2014	0.78	0.83	0.97	na	0.85	0.93	0.49	0.73	0.69	0.58	0.73	0.55	6950
Big Cottonwood (BC)*		1909–2014	0.69	0.75	0.85	0.85	na	0.81	0.51	0.66	0.59	0.52	0.71	0.52	4990
Bear (BR)		1943–2014	0.69	0.71	0.93	0.93	0.81	na	0.61	0.79	0.72	0.61	0.73	0.57	7965
Henry's Fork (HF)**		1929–2014	0.30	0.32	0.48	0.49	0.51	0.61	na	0.54	0.63	0.60	0.66	0.60	6060
Lakefork (LK)		1964–2014	0.51	0.54	0.75	0.73	0.66	0.79	0.54	na	0.84	0.80	0.79	0.69	8180
Yellowstone (YR)		1945–2014	0.44	0.50	0.67	0.69	0.59	0.72	0.63	0.84	na	0.92	0.88	0.78	7430
White Rocks (WR)		1930–2014	0.28	0.32	0.53	0.58	0.52	0.61	0.60	0.80	0.92	na	0.79	0.85	7200
Duchesene (DR)*		1906–2014	0.50	0.58	0.76	0.73	0.71	0.73	0.66	0.79	0.88	0.79	na	0.76	4756
Ashley Creek (AC)**		1915–2014	0.23	0.29	0.54	0.55	0.52	0.57	0.60	0.69	0.78	0.85	0.76	na	6231

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